Robust skin-integrated conductive biogel for high-fidelity detection under mechanical stress

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Introduction

Epidermal electronics require soft conductive materials to seamlessly interface with skin for high-fidelity physiological signal monitoring. However, conventional materials face challenges in conforming to uneven or hairy surfaces and maintaining stability under mechanical stress. Here, we present a skin-integrated conductive biogel that undergoes rapid liquid-to-solid transformation within 3 minutes, enabled by a thermoresponsive gelatin-based network reinforced with PEDOT:PSS and deep eutectic solvents. This design achieves robust mechanical properties (1–3 MPa strength), strong adhesion (~1 MPa), and dual ionic/electronic conduction, ensuring high signal-to-noise ratios (30–40 dB) for precise ECG and EMG detection even during vigorous activities. Our biogel demonstrates exceptional performance in exercise monitoring, muscle recovery tracking, and cardiac signal acquisition, offering a versatile platform for next-generation wearable bioelectronics.

Results

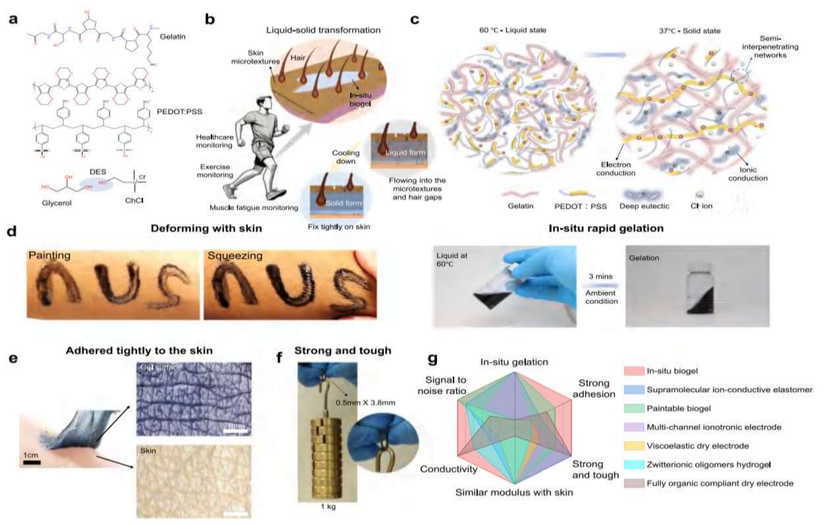


Fig. 1 Illustrating the biogel's liquid-to-solid transition within 3 min, its paintable application conforming to skin micro-textures, strong adhesion, and superior mechanical/electrical benchmarks versus leading soft conductors.

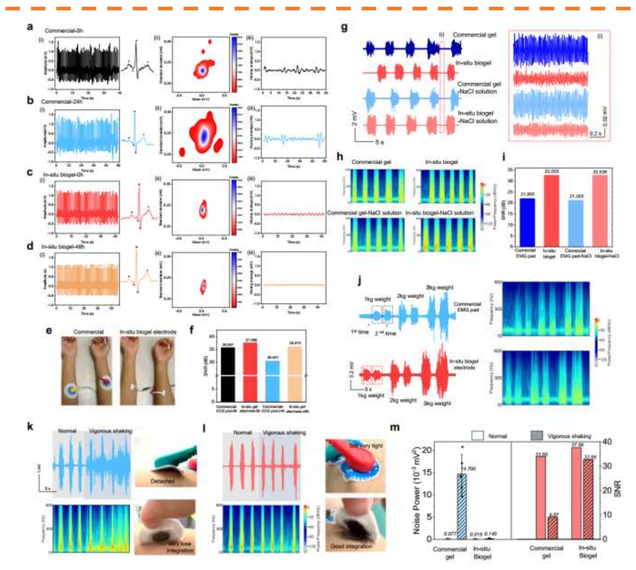


Fig. 4 a-f) The biogel demonstrates superior ECG/sEMG signal stability versus commercial gels, maintaining high SNR (37.5 dB) over 48 hours; **g-j)** It reliably captures muscle activity during weightlifting and resists motion artifacts during vigorous shaking; **k-m)** proving exceptional performance under mechanical stress and sweaty conditions.

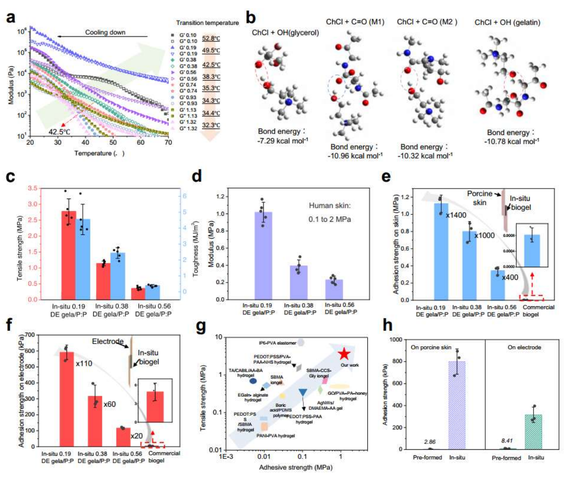


Fig. 2 DES lowers gelation T; 0.38 DE balances strength, modulus, adhesion, 1400× stronger than commercial gels.

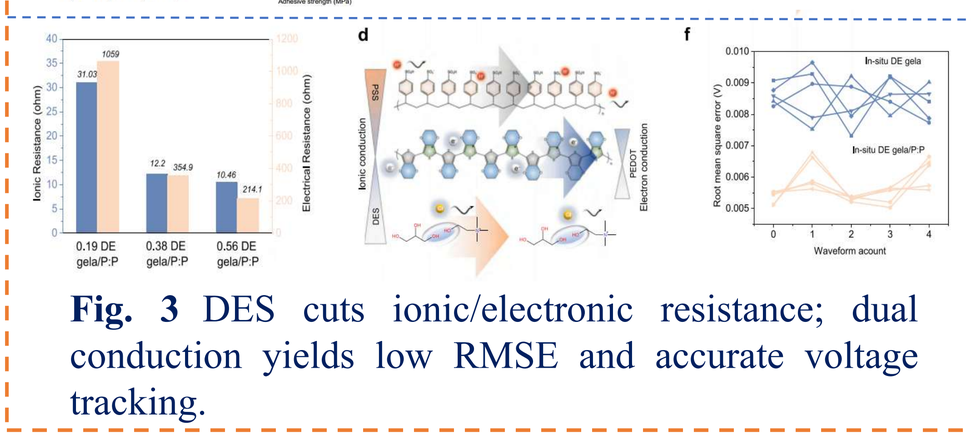


Fig. 3 DES cuts ionic/electronic resistance; dual conduction yields low RMSE and accurate voltage tracking.

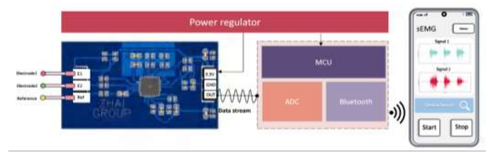
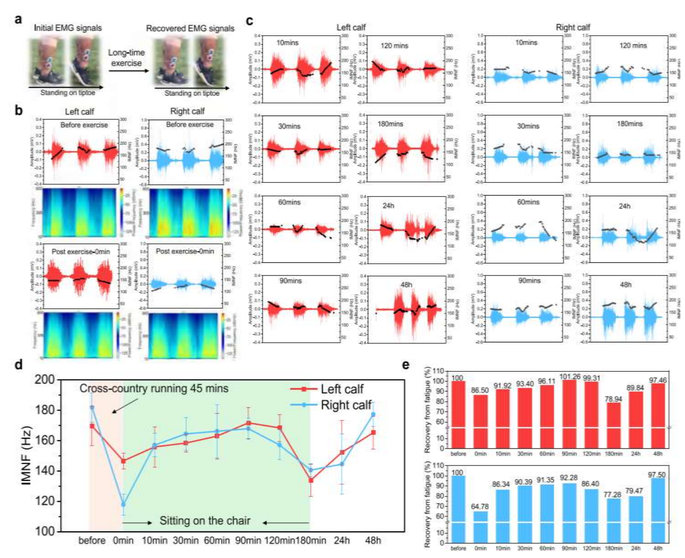


Fig. 6 Tracking calf muscle recovery after 45 min running: sEMG frequency initially drops, rises after 10–90 min rest, dips again at 180 min, then fully rebounds within 48 h, demonstrating quantifiable fatigue-to-recovery dynamics.



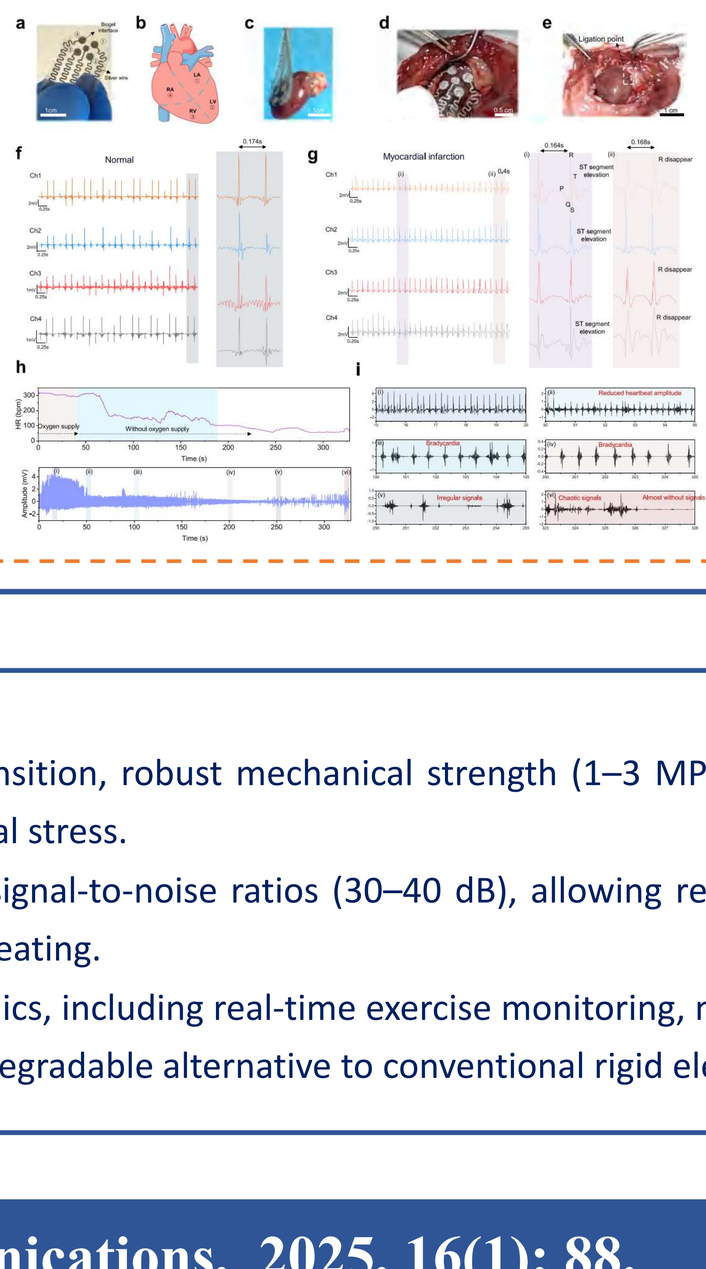


Fig. 8 The biogel cardiac patch successfully monitors real-time heart signals, detecting myocardial infarction through characteristic ST-segment changes and tracking progressive heart failure in rat models.

Conclusion

- The in-situ forming biogel combines rapid liquid-to-solid transition, robust mechanical strength (1–3 MPa), and strong adhesion (~1 MPa), enabling seamless integration with skin even under mechanical stress.
- The dual ionic/electronic conductive pathways ensure high signal-to-noise ratios (30–40 dB), allowing reliable detection of ECG, EMG, and cardiac signals in dynamic conditions, such as exercise and sweating.
- The biogel demonstrates broad potential in wearable electronics, including real-time exercise monitoring, muscle recovery assessment, and in vivo cardiac disease detection, offering a biocompatible and degradable alternative to conventional rigid electrodes.

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