



Optimal conductivity matching for cardiac electrical patches

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Conductive biomaterials are the key interfaces linking biological tissues and flexible electronics, holding essential significance for closed-loop healthcare^[1-3]. They act as electrical conduction bridges to restore electrophysiological communication in damaged tissues and facilitate tissue recovery^[4]. Myocardial infarction (MI) is a prevalent and life-threatening cardiovascular disease^[5], and the associated arrhythmia is a major risk to patients. Since 2015, conductive materials, such as polypyrrole^[6], carbon nanotubes^[5], and reduced graphene oxide^[7], have been investigated for electrical conduction restoration in MI treatment. Besides fundamental properties such as biocompatibility, mechanical compatibility, and adhesion, conductivity is a crucial parameter for cardiac function recovery in therapeutic scenarios^[8,9]. Notably, conductive biomaterials tailored for tissue electrical conduction differ from those designed for signal acquisition and sensing, where low impedance and high signal-to-noise ratios are preferred. However, excessively high conductivity does not guarantee better therapeutic efficacy. Previous studies are limited by narrow tunable range of materials conductivity and insufficient theoretical modeling, leaving the selection of optimal conductivity without systematic evaluation and solid theoretical support.

Recently, Miao *et al.* used conductive graphene oxide aerogel (GA) to prepare highly conductive electroactive cardiac patches (eCarPs) with the conductivity ranging from 10^{-3} to 10^1 S/cm for MI treatment [Figure 1A]^[10]. This range, covering five orders of magnitude, exceeds those reported in existing studies, where the optimal conductivity of eCarP should be 100 to 1,000 times that of native myocardium (10^{-3} S/cm). Such highly conductive eCarPs enable sustained electrocardiogram (ECG) signals. This finding challenges the conventional understanding that “the conductivity of conductive materials should be close to that of healthy myocardium”. Specifically, eCarPs with low conductivity (10^{-3} S/cm) fail to achieve an optimal conduction velocity (CV) [Figure 1B]. To explain this phenomenon, a monodomain model was developed for electrophysiological analysis. Simulation revealed that either excessively low or high conductivity causes mismatch in CV between the eCarP and surrounding healthy myocardium, increasing the risk of reentry with



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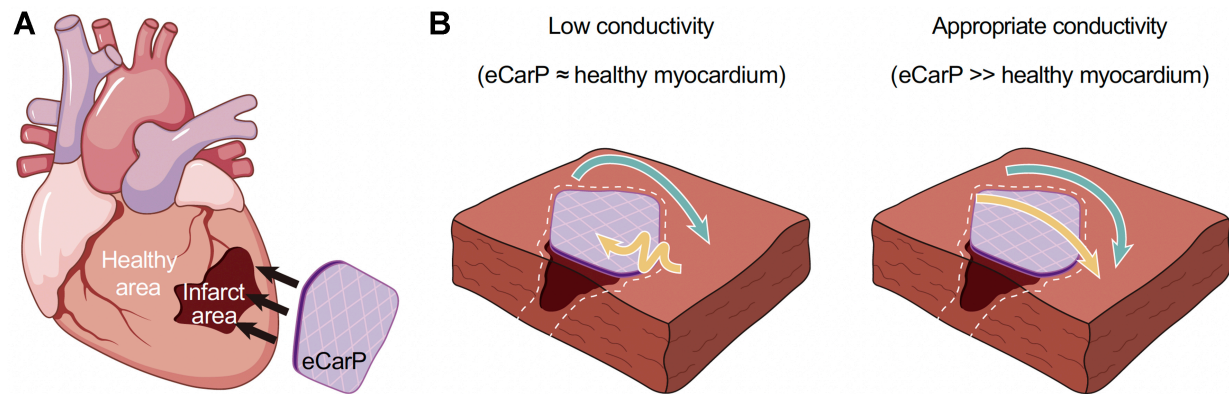


Figure 1. (A) Schematic of eCarP with the relative positions of heart and eCarP; (B) Scheme of eCarPs reducing the risks of arrhythmia. eCarP: Electroactive cardiac patche.

potential lethal arrhythmias. Compared with the resistor–capacitor (RC) model^[11], the monodomain model incorporates physiological constraints on intercellular signal conduction, while it requires a lower computational time than the bidomain model. In the porcine ventricular incision model, the theoretical predictions exhibited high consistency with the experimental results. Accordingly, the monodomain model serves as a practical and accurate tool to interpret electrical interactions between conductive patch and myocardium tissues, providing a solid theoretical basis for further clinical translation.

More interestingly, from the perspective of tissue repair, eCarPs exhibit versatile therapeutic potentials beyond the regulation of abnormal electrical signals^[10]. They can increase ventricular wall thickness, improve cardiac function, facilitate angiogenesis, and upregulate the expression of relevant proteins. Such synergistic effects provide comprehensive biological support for myocardial repair after infarction.

Collectively, investigations into the optimal conductivity of cardiac patches deepen our understanding of how conductive biomaterials restore cardiac electrical synchrony. It also emphasizes that evaluating new-generation biomaterials and biomedical devices requires considerations beyond simple matching of physical properties. The compatibility with the intrinsic characteristics of biological signals is equally important, which acts as a core driving force to advance personalized precision medicine.

Despite the promising therapeutic efficacy of highly conductive biomaterials for MI treatment, there are remaining challenges to be addressed. The adaptability of conductive cardiac patches fundamentally depends on matching the CV of cardiac electrical signals. The myocardial CV is highly dynamic rather than stable, which is strongly dependent on heart rate and susceptible to fluctuations induced by medications, metabolic conditions, and other factors. Further studies are therefore required to validate whether highly conductive patches could maintain stable electrical adaptability under dynamic physiological variations.

Besides therapeutic conduction modulation, cardiac patches also offer potentials for *in-situ* physiological monitoring throughout cardiac treatment and recovery. Various biomaterials can be involved for multimodal sensing platforms, enabling real-time acquisition of bio-signals^[12–14]. Due to their conductivity, cardiac patches can not only be used to sense the intrinsic activities of the heart such as electrophysiological signal and physical deformation, but also monitor key parameters of the cardiac microenvironment, such as temperature and pH levels. The integrated system requires optimizing the structure of the devices to adapt to the dynamic surface of the organ, and overcoming obstacles such as wireless energy supply and signal transmission to ensure the long-term and efficient operation. By integrating electrical conduction therapy with signal sensing within a single patch, such an engineered system can further lower the arrhythmia risks.

Ultimately, this integrated design facilitates a closed-loop health management strategy, featuring continuous monitoring and targeted treatment, which sustains optimal cardiac electrical synchrony and prevents adverse cardiovascular events.

DECLARATIONS

Authors' contributions

Investigation, writing - original draft: Tian, L.

Writing - review and editing, supervision: Song, Y.

Availability of data and materials

Not applicable.

AI and AI-assisted tools statement

Not applicable.

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Conflicts of interest

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Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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REFERENCES

1. Zhao, C.; Park, J.; Root, S. E.; Bao, Z. Skin-inspired soft bioelectronic materials, devices and systems. *Nat. Rev. Bioeng.* **2024**, *2*, 671-90. [DOI](#)
2. Zhou, T.; Yuk, H.; Hu, F.; et al. 3D printable high-performance conducting polymer hydrogel for all-hydrogel bioelectronic interfaces. *Nat. Mater.* **2023**, *22*, 895-902. [DOI PubMed](#)
3. Montazerian, H.; Davoodi, E.; Wang, C.; et al. Boosting hydrogel conductivity via water-dispersible conducting polymers for injectable bioelectronics. *Nat. Commun.* **2025**, *16*, 3755. [DOI PubMed PMC](#)
4. Liang, Y.; Qiao, L.; Qiao, B.; Guo, B. Conductive hydrogels for tissue repair. *Chem. Sci.* **2023**, *14*, 3091-116. [DOI PubMed PMC](#)
5. Wang, L.; Liu, Y.; Ye, G.; et al. Injectable and conductive cardiac patches repair infarcted myocardium in rats and minipigs. *Nat. Biomed. Eng.* **2021**, *5*, 1157-73. [DOI PubMed](#)
6. Mihic, A.; Cui, Z.; Wu, J.; et al. A conductive polymer hydrogel supports cell electrical signaling and improves cardiac function after implantation into myocardial infarct. *Circulation* **2015**, *132*, 772-84. [DOI PubMed](#)
7. Qiu, R.; Zhang, X.; Song, C.; et al. E-cardiac patch to sense and repair infarcted myocardium. *Nat. Commun.* **2024**, *15*, 4133. [DOI PubMed PMC](#)
8. Jalilnejad, N.; Rabiee, M.; Baheiraei, N.; et al. Electrically conductive carbon-based (bio)-nanomaterials for cardiac tissue engineering. *Bioeng. Transl. Med.* **2023**, *8*, e10347. [DOI PubMed PMC](#)
9. Li, Y.; Wei, L.; Lan, L.; et al. Conductive biomaterials for cardiac repair: a review. *Acta. Biomater.* **2022**, *139*, 157-78. [DOI PubMed](#)

10. Miao, Y.; Fu, Z.; Zhang, J.; et al. Theoretical quantitative model and clinical outcome predictions of conductive cardiac patches for electrophysiological treatments. *Nat. Biomed. Eng.* **2026**. DOI PubMed
11. He, S.; Wu, J.; Li, S. H.; et al. The conductive function of biopolymer corrects myocardial scar conduction blockage and resynchronizes contraction to prevent heart failure. *Biomaterials* **2020**, *258*, 120285. DOI PubMed
12. Gu, M.; Guo, C. F.; Song, Y. Multimodal bioelectronics: a pathway to digital health management. *Matter* **2025**, *8*, 102048. DOI
13. Choi, S.; Han, S. I.; Jung, D.; et al. Highly conductive, stretchable and biocompatible Ag-Au core-sheath nanowire composite for wearable and implantable bioelectronics. *Nat. Nanotechnol.* **2018**, *13*, 1048-56. DOI PubMed
14. Nam, S.; Park, C.; Sunwoo, S.; et al. Soft conductive nanocomposites for recording biosignals on skin. *Soft. Sci.* **2023**, *3*, 28. DOI

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