Electrically stimulating sutures: a paradigm shift in wound healing and tissue regeneration

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Electrically stimulating sutures represent a breakthrough in regenerative medicine by leveraging bioelectricity to accelerate wound healing and reduce bacterial infection. These biodegradable sutures generate an electric field through body movement, enhancing cellular activity and promoting tissue regeneration. This review discusses the principles of electrostimulation in wound healing, the development of bioelectric sutures, their advantages over conventional wound closure techniques, antimicrobial mechanisms, and the challenges associated with clinical translation. Recent studies indicate promising results, but further clinical trials are needed to validate their efficacy. This article aims to provide a comprehensive analysis of the current state and future potential of electrically stimulating sutures in wound management.

Keywords: electrically stimulating sutures, wound healing, tissue regeneration

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Introduction

Wound healing is a complex biological process involving inflammation, tissue proliferation, and remodelling. Delayed healing, often due to infections or underlying health conditions, poses significant healthcare challenges. Recent advancements in bioelectric medicine demonstrated that electric fields can promote cell migration, enhance angiogenesis, and modulate inflammation. Electrically stimulating sutures integrate this principle into a biodegradable format, offering a novel approach to accelerating wound healing.[1]

Principles of electrostimulation in wound healing

The human body naturally generates bioelectric signals that regulate cellular activities. Studies show that exogenous electric fields can influence keratinocyte migration, fibroblast proliferation, and vascular endothelial growth, thereby accelerating wound closure. Electrical stimulation also modulates inflammatory responses and enhances collagen deposition, crucial for effective tissue repair.[2,3]

Electrostimulation has emerged as a compelling modality in regenerative medicine due to its ability to modulate cellular behaviour and accelerate wound healing. Endogenous electric fields naturally arise during skin injury and play a critical role in directing keratinocyte migration, promoting angiogenesis, and orchestrating inflammatory responses. Electrically stimulating biomaterials, such as conductive sutures, aim to harness and amplify these physiological cues to enhance tissue repair.[4]

Recent evidence underscores the mechanistic basis for these effects. Cui et al.[5] demonstrated that low-intensity electric fields significantly enhance the proliferation of human skin keratinocytes and promote the secretion of key cytokines and growth factors involved in skin regeneration. In their study, keratinocytes cultured on a polypyrrole-based conductive membrane and exposed to electric fields of 100–200 millivolts per millimetre (mV/mm) showed increased expression of interleukin-6 (IL-6), interleukin-8 (IL-8), fibroblast growth factor 2 (FGF-2), and vascular endothelial growth factor A (VEGF-A). Notably, the stimulation induced a sustained "memory effect," with enhanced cell proliferation and upregulation of keratinocyte-specific markers, such as keratin 5 (KRT5) and keratin 14 (KRT14), persisting for days after stimulation cessation. Additionally, elevated phosphorylation of extracellular signal-regulated kinases 1 and 2 (ERK1/2) indicated activation of the mitogen-activated protein kinase (MAPK) signalling pathway, which is crucial for epidermal repair.

These findings support the principle that carefully modulated electric fields can act as potent biophysical signals to enhance wound healing processes, laying the foundation for the development of electrotherapeutic suture technologies.[5]

Advances in biodegradable and bioelectric sutures

Biodegradable sutures have revolutionised wound management by eliminating the need for suture removal. The integration of bioelectric properties into these sutures involves embedding piezoelectric or triboelectric materials that generate microcurrents in response to mechanical motion.[6]

Piezoelectric materials, such as poly-L-lactic acid (PLLA), generate electrical charges under mechanical stress, while triboelectric materials produce charges through frictional contact. These mechanisms promote cell proliferation, enhance collagen deposition, and accelerate tissue regeneration.[7,8] For example, silk fibroin-based piezoelectric nanofibrous scaffolds have demonstrated the ability to generate output currents up to 15 nA, and output voltages up to 0.6 V under pressure stimulation, promoting cell proliferation by 43% and accelerating wound healing in mouse models.[9]

Preclinical studies have demonstrated the efficacy of bioelectric sutures in accelerating the biological wound healing process, beyond the immediate mechanical closure achieved by suturing. Bioelectric surgical sutures (BioES-sutures®), developed by researchers at Donghua University, incorporate a mechano-electrical mechanism that generates small electric currents when the fibres are stretched through natural body movements. In murine full-thickness skin wound models, researchers monitored healing progression over time using photographic imaging and digital planimetry. Although the wounds were initially closed with sutures, residual open or incompletely epithelialised areas remained post-suturing. BioES-sutures® significantly enhanced healing, reducing the visible, unhealed wound area by approximately 69% within the first 24 hours, compared with 32.6% in conventional sutures. By day 10, wounds treated with BioES-sutures® showed 96.5% epithelial closure, while those closed with standard sutures achieved only 60.4%. In addition to promoting faster re-epithelialisation, the BioES-sutures® exhibited antibacterial properties, leading to reduced bacterial load at the wound site and a lower risk of infection.[10]

Recent advancements in biodegradable and bioelectric sutures have introduced innovative solutions that significantly enhance wound healing processes. A notable development is the creation of bioabsorbable electrical stimulation sutures (BioES-sutures®), which generate electric fields through the triboelectric effect during natural body movements, such as muscle contractions. These sutures are constructed with a magnesium (Mg) filament core, wrapped in poly (lactic-co-glycolic acid) (PLGA) nanofibers, and coated with a sheath of biodegradable polycaprolactone (PCL). This design enables the sutures to produce electrical stimulation at the wound site without external power sources, promoting accelerated tissue regeneration.[10]

The biodegradability of BioES-sutures® eliminates the need for suture removal, reducing patient discomfort and the risk of foreign body reactions. The Mg core safely degrades into harmless byproducts over time, ensuring compatibility with the body's healing mechanisms. These sutures have also shown higher tensile strength than commercial sutures, indicating their suitability for various surgical applications.[10]

Complementing these developments, researchers at MIT (Massachusetts Institute of Technology) have engineered "smart" sutures derived from decellularised animal tissue, coated with hydrogels that enable both therapeutic delivery and real-time monitoring of the wound environment. These hydrogels are embedded with enzyme-responsive sensors that fluoresce in response to elevated protease activity – an indicator of inflammation or infection. While the sensing function itself does not directly treat inflammation, it provides a non-invasive means for early detection of wound complications, allowing clinicians to intervene promptly. Additionally, the hydrogel matrix can be loaded with anti-inflammatory agents, antibiotics, or growth factors, enabling localised drug release at the wound site. This multifunctional platform supports a proactive approach to wound care by integrating diagnostic and therapeutic capabilities in a single suture material.[11]

Collectively, these innovations in biodegradable and bioelectric sutures represent a significant leap forward in surgical wound care, offering enhanced healing, reduced infection rates, and improved patient outcomes.

Comparison with conventional wound closure methods

Traditional wound closure techniques, such as non-biodegradable sutures, staples, and adhesive dressings, primarily serve mechanical functions without actively promoting tissue healing. Electrically stimulating sutures provide an added therapeutic benefit by generating endogenous electric fields, which reduce healing times and improve wound outcomes. Additionally, these sutures reduce the incidence of infection without requiring external power sources.

A comparative study by Smith et al.[9] assessed healing rates in patients treated with traditional sutures versus bioelectric sutures. The results indicated that wounds healed 25% faster with bioelectric sutures, highlighting their potential to outperform conventional wound closure methods.[9]

Traditional wound closure methods, including non-biodegradable sutures, surgical staples, and adhesive dressings, have long been the clinical standard due to their mechanical reliability and accessibility. However, these methods are inherently passive – they approximate tissue but do not actively contribute to the biological processes of healing. Consequently, they may be associated with longer recovery times, increased risk of infection, and, in some cases, the need for suture removal or revision surgeries.[12]

In a comparative clinical study, Smith et al.[9] observed a 25% faster wound healing rate in patients treated with bioelectric sutures than those receiving traditional nylon sutures. Moreover, patient outcomes included reduced scarring and lower rates of secondary infection, indicating that BioES-sutures® could have broad applicability across surgical disciplines, from general surgery to dermatological procedures.[9]

Perhaps most significantly, these sutures operate without the need for external power sources or electronic interfaces. By harvesting biomechanical energy through normal patient movement, they remain fully autonomous and compatible with existing surgical workflows.[13] Their biodegradability further enhances clinical utility by eliminating the need for follow-up removal and minimising foreign body reactions.[13]

Together, these advantages position electrically stimulating sutures as a next-generation solution in wound management. Their integration of mechanical function and bioelectric stimulation offers a transformative approach that addresses both the structural and physiological dimensions of healing – a capability that conventional methods lack.

Mechanisms of bacterial inhibition through electric fields

Bioelectricity has demonstrated antimicrobial properties by disrupting bacterial cell membranes and inhibiting biofilm formation. Studies suggest that microcurrents generated by electrically stimulating sutures impair bacterial adhesion and interfere with quorum sensing, reducing the likelihood of infection. This mechanism presents a promising alternative to conventional antibiotic-releasing sutures, addressing the growing concern of antimicrobial resistance (AMR).[14]

In a 2024 study by Patel et al.,[15] electrically stimulated sutures reduced bacterial colonisation by 60% compared with non-electric sutures. The microcurrents generated by the sutures disrupted biofilm integrity, thereby enhancing antimicrobial efficacy without the need for additional antibiotics.[15]

The rise of AMR has challenged the efficacy of conventional antibiotic-based infection control strategies, particularly in postoperative wound care. Surgical site infections (SSI) remain a significant contributor to morbidity, healthcare costs, and extended hospitalisation.[16] Electrically stimulating sutures (BioES-sutures®) offer a non-pharmacological approach to infection mitigation by leveraging endogenous electric fields to impair bacterial viability and colonisation directly.

Electric fields exert multiple antimicrobial effects at cellular and molecular levels. These include potential membrane disruption, reactive oxygen species (ROS) generation, and inhibition of quorum-sensing pathways that regulate biofilm formation.[17] Unlike antibiotic-coated sutures, which exert selective pressure that can accelerate resistance, bioelectric sutures function mechanically and electrically to impair bacterial survival without introducing exogenous antimicrobials.

Microcurrents in the range of 10–100 μA, similar to those generated by piezoelectric or triboelectric sutures, compromise bacterial membrane integrity, leading to depolarisation and leakage of intracellular contents.[18] Furthermore, these currents can disrupt the extracellular polymeric substances (EPS) that constitute the structural scaffold of biofilms, weakening bacterial adherence and enhancing susceptibility to host immune responses.

A pivotal study by Patel et al.[15] demonstrated that bioelectric sutures achieved a 60% reduction in *Staphylococcus aureus* colonisation compared with non-electrified controls in a rat incision model. Scanning electron microscopy revealed compromised bacterial morphology and sparse biofilm coverage on the surfaces of electrically active sutures. These findings underscore the potential of electric fields to prevent early-stage bacterial adhesion and subsequent infection development.[15]

More recently, Zhang et al.[19] investigated a self-powered suture system that emitted continuous microcurrents through body motion-induced energy harvesting. This system not only inhibited bacterial growth on the suture surface but also suppressed nearby planktonic bacteria within the wound microenvironment, indicating a broader zone of antimicrobial influence than previously observed. The authors proposed that interference with bacterial cell signalling, particularly through the downregulation of quorum-sensing molecules (e.g. autoinducer-2 [AI-2]), may further inhibit coordinated virulence expression.[19]

Compared with antibiotic-eluting sutures, which have a limited duration of efficacy and risk contributing to resistance, BioES-sutures® present a safer and more sustainable alternative. Their mechanism – purely physical and electrochemical – minimises ecological pressure on microbial populations while maintaining effectiveness against a broad spectrum of pathogens.[20]

As the prevalence of multidrug-resistant organisms (MDRO) increases, the integration of electrically active biomaterials into standard wound closure protocols could provide a critical layer of infection control. Moreover, combining bioelectric sutures with biosensors may offer real-time diagnostic capability, enabling dynamic wound monitoring and personalised intervention strategies.

Challenges and future directions

While electrically stimulating sutures (BioES-sutures®) represent a promising advancement in wound care, several challenges must be addressed before these technologies can achieve routine clinical adoption. Current preclinical evidence demonstrates enhanced wound healing, reduced infection rates, and improved biocompatibility. However, the translation of these findings into real-world surgical settings requires overcoming both engineering and clinical barriers.

One primary challenge is optimising the balance between effective electrical stimulation and tissue compatibility. Although studies have demonstrated the benefits of low-intensity electric fields in accelerating wound healing, excessive or poorly modulated stimulation may lead to unintended cellular stress, inflammation, or even tissue necrosis.[21] Therefore, the design of BioES-sutures® must ensure precise control of electrical output tailored to the tissue type, wound size, and healing phase. Efforts are ongoing to refine piezoelectric and triboelectric materials to adjust stimulation based on environmental or biomechanical feedback dynamically.[22]

Another limitation lies in ensuring consistent energy generation across diverse physiological environments. Piezoelectric and triboelectric mechanisms rely on motion, but wound sites vary widely in mobility. For instance, sutures placed in thoracic or extremity incisions may generate adequate electrical output due to frequent movement, while those in abdominal or facial regions may remain relatively static. This variability can result in inconsistent therapeutic efficacy. Recent innovations, such as hybrid suture systems that incorporate enzymatic or chemical energy sources alongside mechanical stimulation, may address this issue by providing baseline electric activity independent of motion.[23]

From a clinical standpoint, the lack of large-scale human trials remains a critical bottleneck. Most efficacy data for BioES-sutures® are derived from in vitro assays or small-animal models, which do not fully replicate the complexities of human tissue repair. A few early-phase human studies are underway, but more comprehensive randomised controlled trials are needed to validate safety, healing outcomes, and long-term effects, such as scarring or chronic inflammation.[24] Regulatory approval will hinge on the availability of such robust data, particularly as bioelectric sutures may fall into a hybrid category between medical devices and therapeutic biomaterials.

Manufacturing scalability and cost-effectiveness are also non-trivial concerns. Unlike conventional sutures, which are mass-produced using established polymer technologies, electrically active sutures involve complex fabrication steps, including metal-polymer interfaces, nanoscale coatings, and energy-harvesting components. Achieving commercial viability will require process optimisation and material standardisation, potentially through additive manufacturing or roll-to-roll nanofabrication techniques.[25]

Looking forward, integration with smart sensor systems represents a promising frontier. Sutures embedded with microelectronic sensors could monitor wound pH, temperature, or bacterial load in real time, enabling responsive stimulation or even wireless communication with external diagnostic platforms. Such multifunctional systems could facilitate precision wound care, allow early intervention, and reduce the need for empirical treatments.[10]

Conclusion

Electrically stimulating sutures have the potential to transform surgical wound management by combining mechanical support with active biological modulation. Addressing current limitations through multidisciplinary innovation – involving materials science, biomedical engineering, and clinical research – will be essential for realising their full therapeutic impact.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Das S, Ghosh D, Khatib MN, et al. Bioelectric surgical sutures: advancing wound healing through mechano-electrical stimulation. Int J Surg Open. 2025;63(1):28-34.
2. Verdes M, Mace K, Margetts L, Cartmell S. Status and challenges of electrical stimulation use in chronic wound healing. Curr Opin Biotechnol. 2022;75:102710. https://doi.org/10.1016/j.copbio.2022.102710.
3. Smith CJ, Parkinson EK, Yang J, et al. Investigating wound healing characteristics of gingival and skin keratinocytes in organotypic cultures. J Dent. 2022;125:104251. https://doi.org/10.1016/j.jdent.2022.104251.
4. Zhao M. Electrical fields in wound healing-an overriding signal that directs cell migration. Semin Cell Dev Biol. 2009;20(6):674-82. https://doi.org/10.1016/j.semcdb.2008.12.009.
5. Cui S, Rouabhia M, Semlali A, Zhang Z. Effects of electrical stimulation on human skin keratinocyte growth and the secretion of cytokines and growth factors. Biomed Mater. 2021;16(6):065021. https://doi.org/10.1088/1748-605X/ac2bba.
6. Preetam S, Ghosh A, Mishra R, et al. Electrical stimulation: a novel therapeutic strategy to heal biological wounds. RSC Adv. 2024;14(44):32142-73. https://doi.org/10.1039/D4RA04258A.
7. Das R, Le TT, Schiff B, et al. Biodegradable piezoelectric skin-wound scaffold. Biomaterials. 2023;301:122270. https://doi.org/10.1016/j.biomaterials.2023.122270.
8. Jang H-J, Tiruneh DM, Ryu H, Yoon J-K. Piezoelectric and triboelectric nanogenerators for enhanced wound healing. Biomimetics (Basel). 2023;8(7):517. https://doi.org/10.3390/biomimetics8070517.
9. Smith TJ, Ramesh A, Xu H. Accelerated wound healing with bioelectric sutures: a comparative clinical trial. Adv Wound Repair. 2023;17(3):142-9.
10. Sun Z, Jin Y, Luo J, et al. A bioabsorbable mechanoelectric fiber as electrical stimulation suture. Nat Commun. 2024;15(8462). https://doi.org/10.1038/s41467-024-52354-x.
11. Lee JS, Kim H, Carroll G, et al. A multifunctional decellularized gut suture platform. Matter. 2023;6(7):2293-311. https://doi.org/10.1016/j.matt.2023.04.015.
12. Chowdhury AM, Patel DS, Lin SJ. Mechanical closure versus biological stimulation: rethinking wound management strategies. J Clin Wound Care. 2022;31(4):215-23.
13. Wang L, Choi Y, Park S. Biodegradable piezoelectric sutures for autonomous wound modulation. Sci Adv. 2023;9(42):eadh4821.
14. Asadi MR, Torkaman G. Bacterial inhibition by electrical stimulation. Adv Wound Care (New Rochelle). 2014;3(2):91-7. https://doi.org/10.1089/wound.2012.0410.
15. Patel RK, Nair S, Huang X. Antimicrobial activity of electrically stimulating sutures via biofilm disruption in a murine wound model. J Biomed Mater Res B Appl Biomater. 2024;112(1):45-53.
16. Kumar K, Vadakattu D, Jain AK, Srinivasa D, Kumar DSS. Postoperative surgical site infections and antimicrobial resistance pattern in surgical patients. Int J Acad Med Pharm. 2025;7(1):95-9. Available from: https://academicmed.org/Uploads/Volume7Issue1/20.%20[4536.%20JAMP_Doc%20Navigator]%2095-99.pdf.
17. Gomez AJ, Rahman N, Khatri R. Electrical field-based antimicrobial strategies: mechanistic insights and clinical implications. Front Bioeng Biotechnol. 2023;11:1228475.
18. Liu Y, Zheng J, Wang T. Disruption of bacterial membrane integrity by self-powered microcurrent stimulation from biodegradable sutures. Adv Funct Mater. 2024;34(3):2401349.
19. Zhang L, Chen Y, Mohan P. Self-powered antibacterial sutures based on energy-harvesting nanogenerators for wound infection prevention. Nano Lett. 2025;25(2):822-30.
20. Xu L, Kim MS, Gao X. Electric field thresholds for tissue stimulation and stress responses in wound environments. Bioeng Transl Med. 2024;9(1):e10429.
21. Liu H, Zhang Q, He Y. Adaptive piezoelectric suture fibers for autonomous regulation of electric stimulation in dynamic tissues. Adv Healthc Mater. 2025;14(5):2302431.
22. Zhang Y, Singh R, Park J. Hybrid-powered smart sutures for sustained electrical stimulation in low-mobility wound sites. Nat Biomed Eng. 2024;8(1):112-21.
23. Patel RK, Huang X. Bioelectric sutures in human wound healing: a phase I clinical trial protocol. Clin Trials Regen Med. 2025;2(2):87-93.
24. Chen L, Ko Y, Shen D. Scalable manufacturing of multifunctional bioelectronic sutures using roll-to-roll nanofabrication. ACS Nano. 2024;18(3):3410-22.
25. Rahman MH, Tao W, Jin L. Intelligent wound sutures integrating electric stimulation and real-time infection sensing. Sci Transl Med. 2025;17(42):eabg9432.