

A piezoelectric polymer coating on percutaneous hearing implants as a novel, device-powered antibacterial strategy

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ABSTRACT

Percutaneous bone-anchored hearing aids (BAHAs) are a highly effective treatment for conductive and mixed hearing loss. However, their clinical success is frequently compromised by high rates of *peri*-abutment infection and subsequent bacterial biofilm formation, which represent a major cause of implant failure and patient morbidity. Current antimicrobial strategies, such as antibiotic-eluting coatings, are limited by finite efficacy and the escalating threat of microbial resistance. It is hypothesized that coating the percutaneous abutment of BAHAs with the piezoelectric polymer polyvinylidene fluoride (PVDF) will confer a dynamic, self-powered antibacterial property. The intrinsic mechanical vibrations generated by the device's sound processor during normal operation will activate the piezoelectric nature of the PVDF. This activation will generate a localized electrical field on the abutment surface sufficient to inhibit the initial attachment of planktonic bacteria and prevent subsequent biofilm formation. This hypothesis presents a plausible, non-pharmacological strategy to mitigate BAHA-related infections by transforming the implant into a "smart" device that leverages its own operational energy for a therapeutic benefit. This approach could significantly improve long-term patient outcomes and has the potential to be adapted as a platform technology for other mechanically active percutaneous medical implants.

Introduction

The clinical utility of percutaneous bone-anchored hearing aids (BAHAs)

Percutaneous bone-anchored hearing aids (BAHAs), also known as osseointegrated auditory implants, represent a transformative technology for patients with conductive hearing loss, mixed hearing loss, or single-sided deafness [1]. These conditions, often resulting from congenital malformations, chronic ear infections, or previous surgeries, render conventional air-conduction hearing aids ineffective or contraindicated. The BAHA system circumvents the compromised outer or middle ear by utilizing the principle of direct bone conduction. An external sound processor captures acoustic signals and converts them into mechanical vibrations. These vibrations are transmitted via a skin-penetrating (percutaneous) titanium abutment to a titanium implant that has been surgically anchored into the mastoid bone [2,3]. The foundation of this system is osseointegration, a process wherein the implant achieves a direct structural and functional connection with living bone, providing a stable and permanent foundation for sound transmission. This direct mechanical coupling ensures high-fidelity sound transmission to the cochlea without the significant signal

dampening that occurs with transcutaneous (through the skin) devices, resulting in superior sound quality and patient outcomes [4,5].

Peri-abutment infection and biofilm formation

The very design feature that confers the BAHA's acoustic superiority, the percutaneous abutment, is also the direct cause of its primary clinical failure mode. The permanent breach of the skin's epithelial barrier creates a persistent portal for microbial ingress, making the implant site highly susceptible to infection. Consequently, adverse skin reactions and infections are the most common and significant complications associated with BAHA implantation. Patients experience adverse skin reactions, with a substantial number requiring revision surgery due to severe or recurrent infections. These complications lead to significant patient morbidity, increased healthcare costs, and, in some cases, the complete abandonment of the device [6–8].

These chronic infections are fundamentally biofilm-related diseases. Common skin commensals, most notably *Staphylococcus epidermidis* and *Staphylococcus aureus*, adhere to the abiotic surface of the titanium abutment [9]. Once attached, these bacteria proliferate and encase themselves in a self-produced extracellular polymeric substance (EPS)

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matrix. This biofilm structure provides a formidable defense, rendering the embedded bacteria more resistant to systemic antibiotics and shielding them from host immune responses. The result is a persistent, low-grade infection that is exceptionally difficult to eradicate, often necessitating implant removal [10,11].

The need for an integrated, long-term antibacterial solution

Current management of *peri*-abutment complications relies on diligent patient hygiene and the reactive use of topical or systemic antibiotics once an infection is established [12]. This approach fails to prevent the initial critical event of bacterial adhesion and contributes to the broader public health crisis of antimicrobial resistance. Therefore, a critical unmet need exists for an integrated, permanent, and non-pharmacological antibacterial surface that can actively prevent biofilm formation over the lifetime of the implant.

The hypothesis

The hypothesis suggests that applying a coating of the piezoelectric polymer PVDF to the skin-penetrating abutment of a bone-anchored hearing aid (BAHA) can provide it with an active, self-powered antibacterial capability. When the device is in use, its sound processor generates mechanical vibrations that trigger a piezoelectric response in the PVDF. This response will generate a localized, oscillating electrical field on the abutment surface that is sufficient to inhibit the initial attachment of planktonic bacteria and prevent the subsequent formation of biofilm, thereby reducing the incidence of *peri*-abutment infections and enhancing long-term implant viability (Fig. 1).

Evaluation of the hypothesis

The credibility of this hypothesis is supported by evidence from materials science, microbiology, and biomedical engineering. A complete evaluation, therefore, requires a detailed examination of the scientific principles that support the concept, followed by a clear and rigorous framework for its experimental validation. Therefore, understanding the rationale behind the hypothesis is critical to formulate evaluation strategies.

Rationale 1: The BAHA system as a consistent source of mechanical stimulation

The primary function of a BAHA is the conversion of acoustic energy into mechanical vibrations, which are then transmitted to the skull [13]. The external sound processor is an electromechanical transducer that is in a state of continuous vibration whenever the device is active [2]. These vibrations demonstrate a broad frequency spectrum which covers the key frequencies for human speech perception.

Rationale 2: Polyvinylidene fluoride (PVDF) as a biocompatible and biostable implant coating

The selection of PVDF is predicated on its well-documented suitability as a long-term implantable biomaterial [14]. PVDF is a highly non-reactive thermoplastic fluoropolymer with a long and successful history of use in demanding biomedical applications, including permanent implants and vascular sutures. It is designated as a USP Class VI plastic, the highest rating for biocompatibility.

The exceptional chemical stability of PVDF, which stems from the

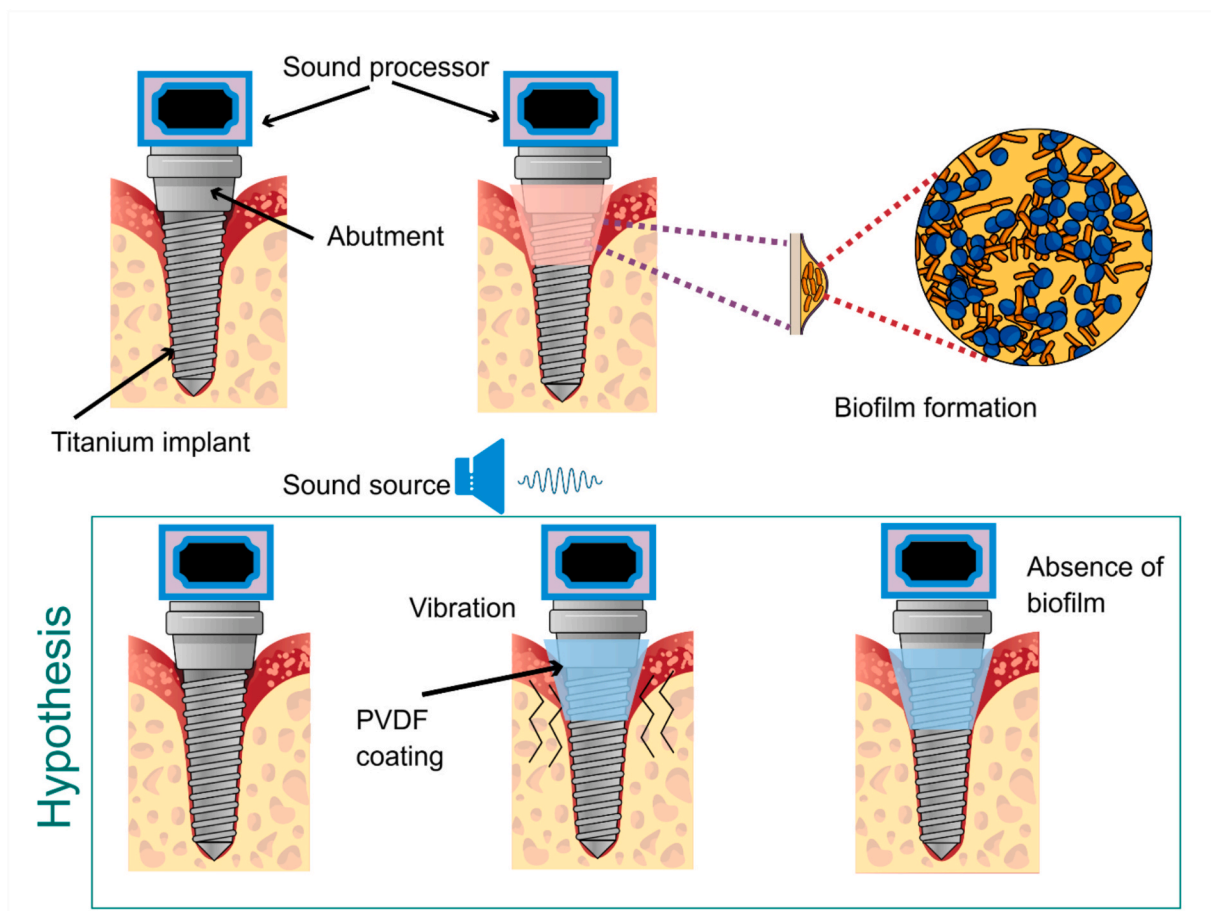


Fig. 1. Schematic of the proposed self-powered antibacterial strategy for percutaneous bone-anchored hearing implants.

high bond energy of its carbon–fluorine bonds, confers outstanding resistance to degradation within the complex and challenging biological environment [15]. A 24-month *in vivo* study in a sheep model directly compared PVDF and polypropylene (PP) surgical meshes. The results showed that while the PP mesh exhibited progressive degradation, cracking, and flaking, the PVDF mesh showed no morphological or chemical signs of degradation over the two-year period [16]. This proven biostability is critical for a permanent implant coating, ensuring that its structural integrity and piezoelectric functionality are maintained for the lifetime of the device. PVDF can be readily processed into thin, conformal films and coatings using established techniques such as solution casting, making it feasible to apply to the complex geometry of a BAHA abutment [17,18]. Its inherent mechanical robustness and high abrasion resistance further ensure the durability of the coating in a dynamic environment.

Rationale 3: Activation of the piezoelectric effect in PVDF by BAHA vibrations

Piezoelectricity is the property of certain materials to generate an electric charge in response to applied mechanical stress. PVDF is one of the most effective and widely studied piezoelectric polymers. This property is derived from its specific crystalline structure. While PVDF can exist in several polymorphs, its strong piezoelectric response is attributed to the polar. β -phase, which has an all-trans (TTTT) chain conformation that results in the alignment of strong C-F molecular dipoles. Standard manufacturing techniques, including mechanical stretching and high-voltage poling, are employed to maximize the β -phase content and create a net macroscopic polarization in the material [19–23].

In the context of this hypothesis, the continuous, low-frequency mechanical strain imparted by the BAHA transducer would cause physical deformation of the crystalline β -phase domains within the PVDF coating. This strain alters the net dipole moment of the material, leading to the accumulation of a dynamic surface charge and the generation of a localized electric field, the direct piezoelectric effect. The device's own operational energy is thus transduced into a therapeutic electrical signal. Here, the therapeutic electrical signal refers to the localized, oscillating electric field generated at the PVDF–abutment interface when the polymer is mechanically deformed by the BAHA's vibrations. This signal represents a transduced electrical stimulus, in which the PVDF converts mechanical energy into electrical energy, rather than functioning as an independent power source.

Rationale 4: The mechanobactericidal action of the piezoelectric surface

The localized electrical field generated on the PVDF surface is hypothesized to inhibit bacterial colonization via at least two distinct, non-mutually exclusive mechanisms. This represents a form of “mechanobactericidal” activity, where mechanical energy is converted into an antimicrobial effect.

The primary proposed mechanism is a physical one, direct membrane disruption (Piezostimulation). The oscillating surface charge generates a localized electric field that directly interacts with the negatively charged components of the bacterial cell envelope, such as teichoic acids in Gram-positive bacteria and lipopolysaccharides in Gram-negative bacteria. This interaction is thought to disrupt the transmembrane potential and increase membrane permeability. In principle this could lead to electroporation-like perturbations of the bacterial envelope. Classical electroporation normally requires short high-voltage pulses. These pulses are in the range of ~50–1500 V across the cell membrane. They are applied over micro- to millisecond time-scales [24], conditions that are not realistically generated by piezoelectric PVDF coatings on BAHAs. The surface potentials produced by mechanically stimulated PVDF are expected to be in the millivolt-to-volt range [25,26]. These are insufficient to induce full electroporation. They

may destabilize local ionic gradients, perturb membrane integrity and synergize with piezocatalytically generated ROS [27]. PVDF and related polymeric transducers produce different electrical outputs depending on their form and stimulation conditions. PVDF vertical cantilevers designed for intra-cochlear pressure can generate voltages above 1 mV. Measured sensitivities show that PVDF cantilevers produce 0.15 mV/Pa at 125 dB SPL. At 150 dB SPL, the output decreases to 0.05 mV/Pa [28]. A PVDF trapezoidal membrane used for acoustic sensing generates 6.3 mV peak-to-peak at 94 dB SPL. This corresponds to a piezoelectric constant of 4.05 pC/N [29]. Another PVDF membrane produced only 16 μ V at 90 dB SPL when tested in silicone oil [30]. Electrospun PVDF fibres are about five times more sensitive to acoustic signals than thin film PVDF. P(VDF-TrFE) membranes tested *ex vivo* in a cochlear setup generated voltages ranging from 0.14 mV to 5.88 mV at 100 dB SPL [31]. These results show that BAHA-related vibrations produce piezoelectric potentials in the millivolt range. The values remain much lower than the 0.2–1 V required for electroporation or membrane disruption. Even sub-volt oscillating fields can trigger interfacial electron transfer. They can also promote mild ROS generation at the polymer–fluid boundary [32–34]. Thus, voltages from BAHA vibration can initiate low-level ROS activity that reduces bacterial adhesion. However, they remain too weak to cause harmful oxidative stress in nearby tissues [33–35].

Piezoelectric voltage outputs from PVDF devices show a wide range. Typical values are in the millivolt range for acoustic or strain sensors [33,36]. Some optimized composites produce much higher open-circuit voltages. For example, 6.06 ± 0.08 V has been reported under mechanical impact. The highest reported *in vivo* voltage from a PVDF nanogenerator was 3.90 ± 0.65 V. This was achieved by harvesting energy directly from cardiac motions [25,37]. High piezoelectric potentials can cause local tissue injury. They do so by generating highly cytotoxic ROS [38]. However, the electrical signals produced by typical BAHA vibrations remain in the low millivolt range. These levels are well below thresholds that could induce tissue damage [26,33,36]. Thus, in this hypothesis, the term ‘electroporation-like’ refers not to classical pore formation but to sub-threshold electrical perturbations that compromise bacterial viability. This piezostimulation is fundamentally different from pharmacological interventions. Because it targets the general structural integrity of the cell membrane rather than a specific metabolic pathway, it is highly improbable that bacteria could develop resistance through single-point mutations [39]. This effect is not universal, as certain electron-accepting bacteria, such as *Geobacter sulfurreducens*, may thrive under particular voltage conditions [40].

An alternative or complementary mechanism involves piezocatalysis. The piezoelectric potential generated on the material's surface can be sufficient to catalyze redox reactions in the surrounding aqueous medium, leading to the generation of highly cytotoxic ROS, such as hydroxyl radicals and superoxide anions [41]. These ROS then indiscriminately attack and damage critical bacterial components, including membrane lipids, proteins, and DNA, leading to cell death. This mechanism has been demonstrated in principle for piezoelectric polymers, where high-frequency ultrasound stimulation of PVDF films led to ROS-mediated antibacterial effects against *Escherichia coli* [42]. Ultrasound excitation differs in magnitude and frequency from BAHA vibrations. Ultrasound excitation typically operates at high frequencies. For example, it uses 1.5 MHz pulsed at 1 kHz, which is much higher than BAHA mechanical vibrations. BAHA vibrations fall within the audible range of 125 Hz to 8 kHz for sound transmission [26,43]. Ultrasound produces localized electrical cues and ROS through acoustic cavitation. This often generates species like hydrogen peroxide (H_2O_2). BAHA mechanical vibration does not produce damaging ROS directly. However, piezoelectric materials responding to similar physiological motion generate electrical signals that influence localized ROS dynamics [25,34,35]. Laboratory tests simulating BAHA vibration showed relatively low PVDF voltage outputs. Values ranged from 25 to 35 mV peak-to-peak [36]. This is much lower than the approximately 750 mV

observed from ultrasound-stimulated PVDF films. These results suggest that BAHA induces only low-energy ROS signaling, which is essential for normal cell function [26,35]. These findings support the plausibility that piezoelectrically induced ROS contribute to bactericidal activity under proper stimulation. Highly cytotoxic ROS include hydroxyl radicals and superoxide anions. They damage human membrane lipids, proteins and DNA. Excessive ROS cause oxidative stress. This directly oxidizes proteins and lipids and damages DNA. The hydroxyl radical is the most potent oxidizer of membrane proteins and lipids. High ROS levels cause inflammation and cellular damage. They can lead to cell death or tissue necrosis. ROS must be controlled within a non-toxic “therapeutic window.” This avoids adverse effects on normal human functions [34]. The body’s natural healing can improve by generating a controlled amount of ROS. This approach has a dual advantage. It kills bacteria at the wound site and creates a sterile environment. At the same time, it promotes recovery through angiogenesis and re-epithelialization. Both are crucial for wound closure. The body sometimes reduces its own ROS-scavenging ability during healing. This allows it to benefit from these effects [35].

However, challenges remain in defining the beneficial range of ROS. The specific roles of ROS in organisms are not fully understood. This knowledge is needed for better material design. It is crucial to consider the therapeutic window of ROS in such designs. ROS-responsive materials must avoid adverse effects on normal cellular functions [34].

The synergy between the device’s inherent function and the proposed therapeutic action is a key strength of this hypothesis. The BAHA must vibrate to work, and a piezoelectric material must generate a charge when vibrated. By combining the two, a self-powered therapeutic function is created without requiring any external energy source or modification to the device’s primary operation, representing a highly efficient and integrated “smart” biomaterial design.

Peri-abutment infections associated with percutaneous BAHAs are common, biofilm-driven, and establish the need for a long-term antibacterial surface. PVDF is a candidate coating due to its biocompatibility and biostability [16]. BAHA sound processors provide a continuous source of mechanical vibration, and the piezoelectric β -phase of PVDF is known to generate a surface charge under mechanical deformation. A growing body of literature links this type of piezoelectric stimulation to antibacterial effects. However, it is not yet proven that the strain from BAHA vibrations can produce a surface potential sufficient for a bactericidal effect *in vivo*. Compared to drug-eluting coatings, a non-leaching piezoelectric surface offers the potential for sustained activity without depletable reservoirs and with a lower risk of resistance. This leads to the hypothesis that a PVDF piezoelectric coating, when activated by BAHA vibrations, can generate local electrical effects strong enough to prevent bacterial attachment and the formation of biofilm on the abutment surface.

The intersection of (i) a well-defined biofilm problem at percutaneous abutments, (ii) PVDF’s implant-relevant material profile, (iii) continuous BAHA-derived mechanical input and (iv) published evidence for piezoelectric antibiosis led to the present hypothesis: a PVDF piezoelectric coating, activated by BAHA vibrations, can generate local electrical effects sufficient to impede bacterial attachment and biofilm formation at the abutment surface.

To move from theoretical plausibility to empirical proof, a complete evaluation requires a rigorous experimental framework to validate the hypothesis, progressing from fundamental *in-vitro* proof-of-concept to a clinically relevant *in-vivo* model. A proposed framework for the evaluation and validation of this hypothesis, progressing from fundamental *in-vitro* proof-of-concept to a clinically relevant *in-vivo* model, is outlined in Table 1.

If validated, this piezoelectric coating strategy could provide a definitive solution to the most significant clinical limitation of percutaneous hearing aids. More broadly, it could serve as a platform technology for a new generation of smart, active, and infection-resistant medical implants that leverage ambient or operational energy to

Table 1

Proposed experimental framework for hypothesis validation.

Stage	Key question	Proposed model/ assay	Primary outcome measure
I	Does mechanical vibration alone, independent of piezoelectric charge generation, influence bacterial adhesion and survival under physiologically relevant conditions?	Compare seven cases. (a) Uncoated titanium abutment under BAHA-relevant vibration. (b) PVDF-coated abutment in non-poled α -phase (NPTi) with vibration. (c) PVDF-coated abutment in non-poled α -phase (NPTi) without vibration (d) PVDF-coated abutment in polarized β -phase (PPTi) with vibration. (e) PVDF-coated abutment in polarized β -phase (PPTi) without vibration. (f) Polypropylene-coated abutment without vibration. f) Polypropylene-coated abutment with vibration. Conduct assays under oxygen levels mimicking <i>in vivo</i> conditions. Include ionic environments relevant to tissue. Capture bacterial growth differences across the 7 cases.	Bacterial adhesion (CFU counts), viability (Live/Dead staining, SEM). Parallel assays of mammalian cell compatibility (osteoblasts, fibroblasts, keratinocytes) to ensure antibacterial effects are not accompanied by host cytotoxicity.
II	Is the antimicrobial effect from direct piezostimulation, piezocatalytically generated ROS, or a synergistic combination?	To dissect the mechanisms, the following three parallel experiments will be conducted: 1. Test for combined effect: A standard assay will be run using the vibrating, piezoelectric PVDF-coated abutment to measure the total antibacterial activity and quantify ROS. 2. Test for piezostimulation only: The assay will be repeated in the presence of an ROS scavenger (e.g., mannitol) to neutralize the ROS, thereby isolating the effect of the direct electrical field. 3. Test for ROS only: The assay will be done without giving vibration and providing external ROS, thereby isolating the effect of ROS. External ROS will be added as a positive control. Examples include hydrogen peroxide (about 100 μ M) or Fenton-	By comparing the bactericidal efficacy across the three conditions, the relative contribution of piezostimulation and ROS can be determined.

(continued on next page)

Table 1 (continued)

Stage	Key question	Proposed model/ assay	Primary outcome measure
III	Does a PVDF coating on a percutaneous implant reduce infection rates in a relevant animal model?	generated hydroxyl radicals. These concentrations can kill bacteria but are safe for normal cells. This test will compare known ROS effects with those from BAHA-stimulated PVDF. It helps confirm if the ROS produced by PVDF is strong enough for antibacterial action. A rabbit model of percutaneous, bone-anchored implant infection. Custom-fabricated titanium implants (PVDF-coated vs. uncoated controls) are placed in the tibia, penetrating the skin. The implant site is then challenged with a defined inoculum of bacterial strain.	Assessment of clinical signs of infection (e.g., erythema, swelling, purulence). Histological analysis of the skin-implant interface and underlying bone. Quantitative microbiology (CFU counts) from explanted abutments and surrounding tissues.

perform autonomous therapeutic functions.

In evaluating this hypothesis, it is also important to consider the potential impact of piezoelectrically generated ROS on host tissues. While ROS are well recognized for their antimicrobial activity, excessive or chronic exposure can also damage mammalian lipids, proteins, and DNA, potentially leading to inflammatory or cytotoxic responses.

Consequences of the hypothesis and discussion

If validated, this hypothesis could transform the management of percutaneous hearing implants. A successful piezoelectric antibacterial coating would be expected to dramatically reduce the incidence of *peri*-abutment infections, skin overgrowth, and subsequent implant failure. This would directly translate to improved patient safety, reduced morbidity, a decreased need for costly and burdensome revision surgeries, and a significant reduction in the clinical use of antibiotics, thereby aligning with global antimicrobial stewardship efforts. By fundamentally improving the safety profile of percutaneous devices, this technology could also broaden their application to patients who are currently considered high-risk for infectious complications.

This concept exemplifies a paradigm shift in medical implant design, moving from passive, bio-inert materials to active, “smart” biomaterials that intelligently interact with their physiological environment. The principle of harnessing a device’s own operational energy for a secondary, autonomous therapeutic purpose is a novel and powerful concept. This approach could serve as a platform technology, adaptable to other mechanically active implants where biofilm formation is a concern, such as orthopedic joint prostheses (subjected to micromotion from load-bearing), dental implants (subjected to mastication forces), or even components of ventricular assist devices (subjected to pulsatile flow).

The proposed piezoelectric PVDF coating offers compelling theoretical advantages over the two most common classes of antimicrobial coatings: those that elute antibiotics and those that elute silver ions. Antibiotic-eluting coatings are fundamentally limited by a finite drug reservoir, which depletes over time, and they carry the significant risk of

promoting the evolution of antibiotic-resistant bacterial strains [44]. Silver-based coatings, while having broad-spectrum activity, rely on the leaching of silver ions, which raises concerns about long-term host cell cytotoxicity and potential depletion of the active agent. Furthermore, while less common than antibiotic resistance, microbial resistance mechanisms to silver have been documented [44–46]. The proposed piezoelectric strategy is non-leaching, its activity is theoretically indefinite (lasting as long as the device functions), and its primary physical mechanism of action is inherently robust against the development of microbial resistance.

Limitations of the hypothesis

While scientifically reasonable, the hypothesis has some key limitations that must be acknowledged and addressed through future research. The primary limitation is that this manuscript presents a theoretical construct derived from synthesizing disparate lines of evidence. The complete causal chain from BAHA vibration, to PVDF charge generation, to a clinically significant bactericidal effect has not been demonstrated directly and requires rigorous empirical validation. A critical uncertainty is whether the magnitude of mechanical strain produced by a BAHA transducer is sufficient to generate a surface potential that has a robust antimicrobial effect in a complex biological environment. The presence of proteins and electrolytes in the *peri*-implant fluid could screen the generated surface charge, potentially diminishing its efficacy. The precise surface potential required for bactericidal versus bacteriostatic activity is not well defined, and the picoampere-level currents generated may prove to be insufficient for complete bacterial eradication.

The hypothesis involves the chronic application of a low-level, oscillating electrical field to the adjacent soft tissue and bone. The long-term biological consequences of this stimulation are unknown [47]. While some research suggests that certain electrical stimulation regimens can be beneficial for bone healing and osteogenesis [48], other studies have shown inconclusive or even inhibitory effects on cellular differentiation [49]. The current experimental framework advances directly from *in vitro* bacterial assays to an *in vivo* rabbit model. An important intermediate step will be to evaluate mammalian cell responses to piezoelectrically induced ROS and oscillating fields. Relevant cell types include osteoblasts, fibroblasts, and keratinocytes at the skin-implant interface. Assays of cell viability, oxidative stress, and differentiation will help ensure that antibacterial effects do not come at the expense of host tissue compatibility. The specific effects are highly dependent on the electrical parameters (frequency, current, duration), and the potential for unintended alterations in local tissue homeostasis or inflammation over many years must be carefully considered.

ES represents an emerging therapeutic approach for various medical conditions, including wound healing, by influencing the physiological and pathological processes within the body. Damage to the skin creates a lateral electric field, with the wound edge typically being more positive than the center, though this field is observed to be weaker in chronic wounds, such as those in diabetic mice. Therapeutic electrical stimulation aims to harness or replicate the healing benefits of this natural endogenous electric field [50]. Despite its promising potential, the therapeutic application of ES faces several challenges, particularly concerning safety and efficacy. The therapeutic application of ES faces challenges in safety and efficacy. Stimulation-induced tissue damage is a major constraint. Intensity is often assessed by charge density and charge per phase of a stimulus pulse. The Shannon equation helps assess damage thresholds in macroelectrodes. For microelectrodes the safety parameters may differ from macroelectrodes. Emerging applications may need charge densities beyond traditional limits without causing damage [51]. A major bottleneck in chronic wound healing is limited knowledge of *in vivo* electrical transduction. Current sensors capture only surface data and miss the deeper dermis. *In vitro* models provide control but lack consistent stimulus characterization. This makes

translation difficult. Optimizing electrical stimulus is crucial since cells from chronic wound patients may respond differently from healthy cells. Interdisciplinary efforts are needed to build accurate models and characterize cellular responses under chronic wound conditions [50].

The practical realization of this concept hinges on overcoming significant manufacturing hurdles. Creating a durable coating of β -phase PVDF that maintains strong adhesion to the underlying titanium abutment is critical. Delamination of the coating would result in a complete loss of function. The manufacturing process must be precisely controlled to ensure a high, uniform, and stable concentration of the piezoelectric β -phase, which is essential for the coating's antimicrobial activity.

Conclusion and future directions

This paper puts forth the hypothesis that coating the percutaneous abutment of bone-anchored hearing aids with piezoelectric PVDF can create a self-powered, anti-infective surface. This novel approach takes advantage of the device's inherent operational vibrations to generate a localized electrical field, which in turn prevents bacterial colonization and biofilm formation via a non-pharmacological, physical mechanism. The scientific credibility of this hypothesis is built upon a strong foundation in materials science, microbiology, and medical device engineering. The potential clinical impact of this technology warrants a dedicated and rigorous experimental investigation.

Ethics statement

This study does not involve human participants, animal subjects, or clinical trials, and therefore does not require ethical approval.

Consent for publication

Not applicable, as no human or animal data requiring consent was used in this manuscript.

Data availability

No new data were generated or analyzed.

CRedit authorship contribution statement

K.P. Khadeeja Thanha: Writing – review & editing, Writing – original draft, Software, Resources, Methodology, Investigation, Data curation, Conceptualization.

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Declaration of competing interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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