IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 25, Issue 8 Ser. 1 (August. 2026), PP 80-84
www.iosrjournals.org

Triboelectric Dental Restorative Materials: Harnessing Mechanical Energy For Smart Oral Therapeutics

Lakshmi Sunkara
Post Graduate, Department Of Conservative Dentistry And Endodontics
CKS Teja Institute Of Dental Sciences And Research
Tirupati 517501, Andhra Pradesh, India

Sunil Kumar Chennuru
Professor And HOD
Department Of Conservative Dentistry And Endodontics
CKS Teja Institute Of Dental Sciences And Research
Tirupati -517501, Andhra Pradesh, India

P Nihar
Senior Lecturer
Department Of Conservative Dentistry And Endodontics
CKS Teja Institute Of Dental Sciences And Research
Tirupati -517501, Andhra Pradesh, India

S Mohan Kumar Reddy
Senior Lecturer
Department Of Conservative Dentistry And Endodontics
CKS Teja Institute Of Dental Sciences And Research
Tirupati-517501, Andhra Pradesh, India

K Sudharshanan Chandrasekaran
Senior Lecturer
Department Of Conservative Dentistry And Endodontics
CKS Teja Institute Of Dental Sciences And Research
Tirupati -517501, Andhra Pradesh, India

Shaik Hakeem
Senior Lecturer
Department Of Conservative Dentistry And Endodontics
CKS Teja Institute Of Dental Sciences And Research
Tirupati -517501, Andhra Pradesh, India

Abstract
Dental restorations continually experience the mechanical energy of mastication, an abundant and largely untapped power source within the oral cavity. Triboelectric nanogenerator (TENG) technology, which converts mechanical stimuli into electrical output via contact electrification and electrostatic induction, has recently been explored for oral health monitoring, self-powered occlusal-force sensing, and antibacterial biomaterials, but its deliberate integration into load-bearing dental restorative materials remains an emerging concept rather than an established clinical technology. This review synthesizes current literature on triboelectric and related piezoelectric energy-harvesting biomaterials with relevance to dentistry, and proposes a conceptual framework for "smart" triboelectric restorative composites capable of self-powered sensing, electrically assisted antibacterial action, and on-demand therapeutic release. We summarize TENG operating modes, candidate filler and layer systems reported in adjacent biomedical literature, and the principal translational barriers-biocompatibility, mechanical durability in a wet oral environment, miniaturization, and regulatory validation-that must be addressed before such materials could reach clinical use. We conclude that while no clinically validated triboelectric dental restorative material yet exists, the convergence of TENG engineering, dental

biomaterials science, and minimally invasive dentistry constitutes a plausible and testable direction for future self-powered, responsive oral therapeutics.

Date of Submission: 01-08-2026 Date of Acceptance: 11-08-2026

I. Introduction

Dental caries and restorative failure remain leading causes of tooth structure loss worldwide, and resin-based composite restorations-despite decades of refinement-continue to show comparatively high long-term failure rates driven by secondary caries, marginal microleakage, and bulk fracture.

A parallel body of engineering research has matured around triboelectric nanogenerators (TENGs), devices that convert otherwise-wasted mechanical energy-vibration, friction, pressure-into usable electrical output through coupled contact electrification and electrostatic induction. Because TENGs can be built from flexible, biocompatible, and even biodegradable materials, they have been adapted for a growing range of biomedical applications, including wearable and implantable self-powered sensors, wound-healing systems, drug-delivery microneedles, and antibacterial surfaces.

The oral cavity presents a distinctive opportunity for this technology: teeth are subjected to hundreds of thousands of occlusal loading cycles annually, and the restoration-antagonist tooth interface is, in effect, a natural contact-separation triboelectric pair. Recent proof-of-concept work has already demonstrated battery-free, triboelectric occlusal-force sensors and biowaste-derived triboelectric oral health monitors, and piezoelectric nanofillers have separately been incorporated into dental resin composites to achieve combined antibacterial and remineralizing effects through stress-induced electric fields. These developments motivate the central question addressed in this review: could triboelectric principles be deliberately engineered into the restorative material itself, rather than into an adjunct sensor, to create a self-powered "smart" restoration capable of sensing, antimicrobial action, and therapeutic delivery?

This review (i) outlines the fundamental operating modes of TENGs relevant to an occlusal environment, (ii) surveys biomaterial systems from the wider TENG and dental-composite literature that could plausibly be adapted into a triboelectric restorative material, (iii) proposes a conceptual system-level framework for such a material, and (iv) critically discusses the biological, mechanical, and regulatory barriers to clinical translation.

Fundamentals of triboelectric energy conversion relevant to occlusion

TENGs generate electrical output through cyclic contact and separation (or sliding) between two materials of differing electron affinity, producing equal and opposite triboelectric charges at the contacting surfaces; separation of the charged surfaces then drives electron flow through an external circuit to balance the induced potential difference. Four canonical operating modes have been described in the TENG literature and map onto distinct aspects of oral biomechanics (Table 1).

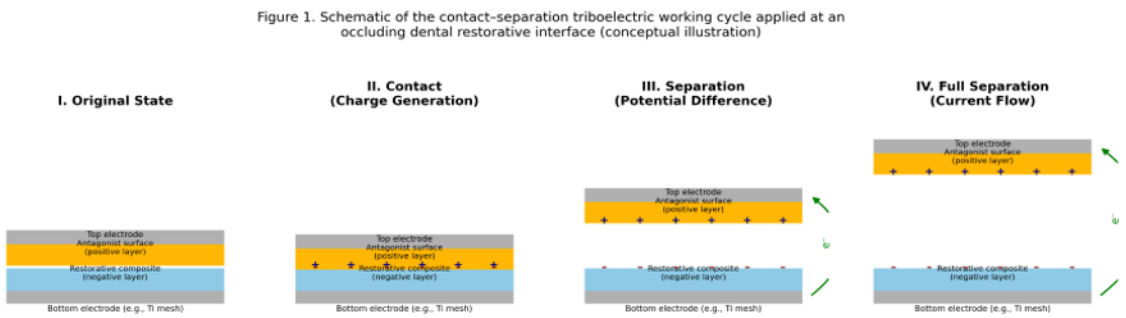

Figure 1. Schematic of the contact-separation triboelectric working cycle as it could occur at an occluding dental restorative interface (conceptual illustration; not derived from experimental data).

Table 1. Triboelectric nanogenerator operating modes and their conceptual relevance to the occlusal environment

Operating mode	Basic structure	Relative output characteristics	Relevance to intraoral / restorative use
Contact–separation (vertical)	Two dissimilar dielectric/electrode layers brought into and out of contact	High instantaneous voltage; moderate current; simple structure	Matches cyclic occlusal loading during mastication and bruxism
Single-electrode	One triboelectric layer with a single electrode referenced to ground	Lower output but no wiring to the moving counter-surface needed	Practical when the antagonist tooth/food bolus cannot carry an electrode
Lateral-sliding (freestanding)	Layers slide laterally across one	Continuous, higher-frequency	Suited to shear/sliding

Operating mode	Basic structure	Relative output characteristics	Relevance to intraoral / restorative use
	another	output during sliding contact	components of chewing and parafunctional grinding
Contact–freestanding triboelectric layer	A freestanding charged layer moves between two stationary electrodes	Stable output largely independent of contact force magnitude	Potentially useful where bite-force variability is high (e.g., bruxism)

From adjunct sensors to an integrated restorative material

Most existing dental applications of triboelectric technology have used the TENG as a separate, adjunct sensing device rather than as the restorative material itself. A flexible, battery-free occlusal-force sensor array based on complementary semicircular electrodes has been shown to capture static and dynamic bite forces with an average sensitivity of approximately 0.72 V/N and a 15-millisecond response time, illustrating the feasibility of intraoral triboelectric sensing. Biowaste-derived TENGs built from cellulose, chitosan, and gelatin composites have similarly been proposed for sustainable, battery-free oral health and bite-pattern monitoring.

A conceptually related but mechanistically distinct approach has embedded piezoelectric barium titanate (BaTiO3) nanofillers directly into dental resin composites; occlusal loading generates localized electric fields that reduced biofilm growth by up to roughly 90% in vitro and promoted formation of dense calcium phosphate mineral layers at the composite surface, demonstrating that a load-bearing restorative material can itself be made electrically active without an external power source. Separately, ZnO-functionalized paper-based triboelectric layers and antibacterial bromobutyl-rubber TENGs have shown that contact-electrification surfaces can be engineered for intrinsic antibacterial activity against organisms such as Escherichia coli and Staphylococcus aureus.

Table 2 summarizes representative material systems drawn from this adjacent literature that, in our assessment, constitute plausible building blocks for a genuinely integrated triboelectric dental restorative material-one in which the filler/matrix system of the composite itself performs both the mechanical, load-bearing function of a conventional restoration and the electrical, contact-electrification function of a TENG.

Table 2. Candidate biomaterial systems relevant to a triboelectric dental restorative composite

Candidate filler / layer system	Proposed mechanism	Reported / anticipated function	Representative source
Barium titanate (BaTiO3) piezoelectric nanofillers in resin composite	Stress-induced polarization and localized electric fields at the tooth-restoration interface	Biofilm reduction (~90% in vitro) and enhanced calcium phosphate remineralization	Montoya et al., ACS Appl Mater Interfaces, 2021
ZnO-functionalized cellulose paper / PTFE triboelectric pair	Contact electrification generating sustained negative surface charge	Antibacterial activity against E. coli and S. aureus; candidate for implant/restorative surfaces	Wang et al. review, PMC, 2024
Bromobutyl-rubber-based antibacterial TENG	Elastomeric contact-electrification layer with intrinsic antimicrobial rubber matrix	Self-powered antibacterial wearable sensing, adaptable concept for intraoral devices	Zhang et al., Nano Energy, 2021
Biowaste-derived PVA-chitosan-gelatin composite TENG	Natural biopolymer triboelectric layers on edible/biodegradable substrates	Battery-free oral health/bite-pattern monitoring	Panda et al., ACS Appl Mater Interfaces, 2023
Flexible occlusal-force TENG sensor array	Complementary semicircular electrode arrays under occlusal load	Real-time quantitative occlusal force mapping (0.72 V/N sensitivity)	Materials Today Communications, 2024

Proposed conceptual framework

Building on these precedents, we propose a layered conceptual framework (Figure 2) in which a triboelectric restorative composite performs four sequential functions: (1) harvesting mechanical energy from mastication and parafunctional activity such as bruxism at the restoration-antagonist interface; (2) generating and rectifying triboelectric charge within an embedded filler-matrix system; (3) routing the harvested charge to one or more therapeutic or diagnostic outputs, including self-powered occlusal-force or bruxism sensing, electrically triggered antibacterial or ion-release action, and on-demand delivery of remineralizing or antimicrobial agents; and (4) closing a feedback loop that could, in principle, inform clinician- or patient-facing monitoring of restoration status and oral health over time.

Figure 2. Conceptual framework for a triboelectric smart dental restorative system

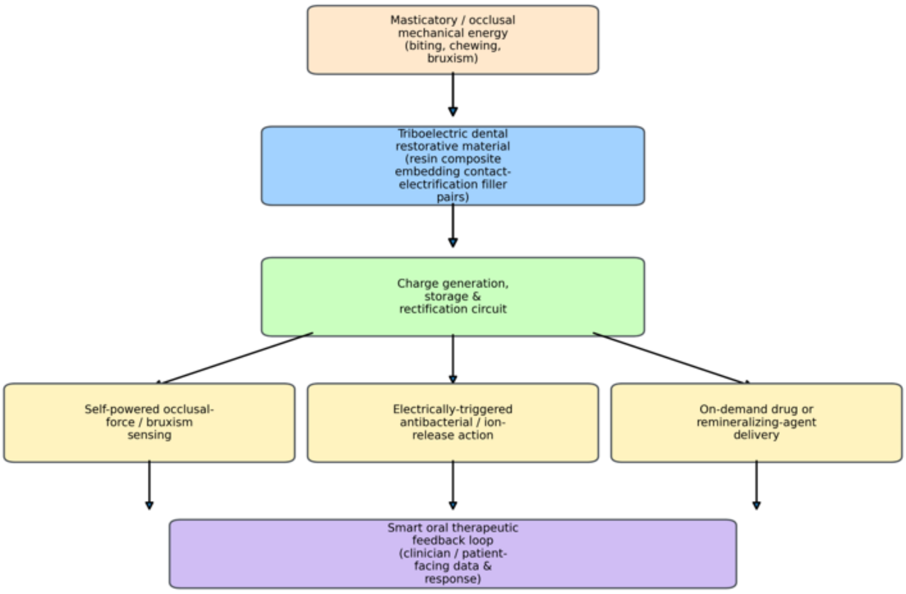

Figure 2. Conceptual framework for a triboelectric smart dental restorative system, illustrating the proposed pathway from occlusal mechanical input to sensing and therapeutic output. This framework is a synthesis proposed by the authors for future testing and has not been experimentally validated as an integrated system.

It is important to emphasize that, to our knowledge, no single published material has yet combined all four elements of this framework within one restorative composite validated in vivo; the framework is instead a synthesis of separately demonstrated components (occlusal energy harvesting, electroactive antibacterial fillers, and self-powered oral sensors) intended to guide future experimental work.

II. Translational Challenges And Limitations

Several substantial barriers separate the conceptual framework above from a clinically usable material, spanning biocompatibility, mechanical performance in the wet and chemically dynamic oral environment, device miniaturization, and regulatory pathways (Table 3).

Table 3. Key translational challenges for triboelectric dental restorative materials

Domain	Key challenge	Possible mitigation strategies
Biocompatibility	Long-term cytotoxicity and ion leaching of filler/electrode materials in the oral cavity is not established	Systematic ISO 10993-based biocompatibility testing; encapsulation with biocompatible dielectrics
Mechanical durability	Restorations undergo cyclic occlusal loads >100,000 cycles/year; triboelectric interfaces may fatigue or delaminate	Fatigue testing under simulated mastication; optimized filler-matrix bonding
Moisture and humidity	Saliva is a conductive, humid environment that can short-circuit or dampen triboelectric output	Hydrophobic encapsulation layers; humidity-tolerant material pairs
Miniaturization and encapsulation	Restorations occupy millimeter-scale cavity preparations, limiting electrode/circuit space	Thin-film electrodes; integration with existing adhesive/composite layering
Regulatory and clinical validation	No clinical-grade triboelectric restorative product has completed regulatory review	Staged preclinical-to-clinical translation pathway; collaboration with dental device regulators

A further methodological limitation is that most of the supporting literature cited in this review originates from the broader biomedical and wearable-electronics TENG field, or from piezoelectric (rather than strictly triboelectric) dental composites; direct, restoration-specific triboelectric material data in a masticatory-load, saliva-immersed model are still lacking. Any translational program would need to establish standardized in vitro chewing simulators combined with electrochemical and antibacterial endpoints before in vivo or clinical evaluation could be justified.

Future directions

Priority research directions include: (i) direct incorporation and testing of contact-electrification filler pairs (e.g., functionalized ceramic or ZnO-based particles) within clinically relevant resin-composite matrices under simulated occlusal loading; (ii) coupling of harvested charge to controlled, low-dose release of antibacterial or remineralizing agents rather than continuous passive release; (iii) integration with existing self-powered occlusal-force sensor architectures to enable simultaneous restoration monitoring and therapeutic action; and (iv) systematic biocompatibility and fatigue testing aligned with dental-material regulatory standards. Interdisciplinary collaboration between materials engineers, restorative dentists, and microbiologists will be necessary to move from the proof-of-concept components reviewed here to an integrated, clinically validated product.

III. Conclusions

Triboelectric energy harvesting has been successfully demonstrated in adjunct oral sensors and in electroactive (largely piezoelectric) dental composites, establishing that the mechanical energy of mastication can be converted into clinically useful electrical signals and biological effects within the oral cavity. A fully integrated triboelectric dental restorative material-one that simultaneously restores tooth structure and generates therapeutically or diagnostically useful electrical output from normal chewing forces-remains a conceptual, testable proposal rather than a validated clinical reality. Addressing the biocompatibility, durability, miniaturization, and regulatory challenges identified in this review will be essential to determine whether such "smart" self-powered restorations can move from concept to clinical practice.

Additional Information

Disclosures: This manuscript was prepared as an AI-assisted literature review and conceptual synthesis at the requester's direction. It does not report original laboratory or clinical data. All cited findings are attributed to the original published sources listed in the References section; readers should consult primary sources before clinical or research application. No human or animal subjects were involved. No funding was received for this work.

References

[1]. Panda S, Hajra S, Mistewicz K, Et Al. Sustainable Solutions For Oral Health Monitoring: Biowaste-Derived Triboelectric Nanogenerator. ACS Appl Mater Interfaces. 2023.
[2]. Wei X, Wang Q, Et Al. Biomaterial Promotes Triboelectric Nanogenerator For Health Diagnostics And Clinical Application. Int J Mol Sci / PMC. 2024;PMC11643059.
[3]. Zheng Q, Zhang H, Shi B, Et Al. Triboelectric Nanogenerator For Healthcare And Biomedical Applications: From Bone Regeneration To Self-Powered Stimulation Systems. Nano Energy / Biomaterials. 2020.
[4]. Li H, Yang X, Et Al. A Flexible Self-Powered Occlusal Force Sensor Array For Assisting Oral Occlusion Reconstruction. Mater Today Commun. 2024.
[5]. Sun Q, Zhang L, Bai R, Et Al. Recent Progress In Antimicrobial Strategies For Resin-Based Restoratives. Polymers (Basel). 2021;13(10):1590.
[6]. Zhang W, Zhang Y, Yang G, Hao X, Lv X, Wu F, Liu J, Zhang Y. Wearable And Self-Powered Sensors Made By Triboelectric Nanogenerators Assembled From Antibacterial Bromobutyl Rubber. Nano Energy. 2021;82:105769.
[7]. Jasmine S, Krishnamoorthy R, Gnanasagar A. Antimicrobial Fillers For Dental Restorative Materials. In: Antimicrobial Materials For Biomedical Applications. 2021:359-392.
[8]. Chen Y, Et Al. A Review Of New Generation Of Dental Restorative Resin Composites With Antibacterial, Remineralizing And Self-Healing Capabilities. Discov Nano. 2024;19:150.
[9]. Montoya C, Jain A, Correa S, Lelkes PI, Melo MAN, Orrego S. Multifunctional Dental Composite With Piezoelectric Nanofillers For Combined Antibacterial And Mineralization Effects. ACS Appl Mater Interfaces. 2021.
[10]. Choi D, Et Al. Soft Ionic And Electronic Triboelectric Nanogenerators: Toward Attachable And Implantable Biomedical Applications. Adv Mater. 2026.
[11]. Wang W, Fu C, Du Y, Et Al. Aqueous-Aqueous Triboelectric Nanogenerators Empowered Multifunctional Wound Healing System With Intensified Current Output For Accelerating Infected Wound Repair. Adv Healthc Mater. 2024;13:2401676.
[12]. Bok M, Lee Y, Park D, Et Al. Microneedles Integrated With A Triboelectric Nanogenerator: An Electrically Active Drug Delivery System. Nanoscale. 2018;10:13502.
[13]. Shi F, Li C, Du J, Han Q, Zhang F, Lee MG, Kim D, Wang K, Xu L, Kim JS. Integrated Oral Wearable Devices: From Smart Sensing To Closed-Loop Theranostics. Coord Chem Rev. 2026;557:217750.
[14]. El Naggar RAE, Elebiary MA, Kenawy E, Elolimy GA. Synthesis And Evaluation Of A Novel Antibacterial Nanocomposite Resin Restorative Material. Tanta Dent J. 2025;22(3):439-451.

Note on citation verification: Given the emerging and cross-disciplinary nature of this topic, readers should independently verify each reference against the original source (journal website or PubMed/PMC record) before citing this manuscript in further academic work, as bibliographic details for very recent (2025-2026) publications may be refined after initial online publication.