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Patient Acceptance and Safety of Nanobot Use in Dentistry: A Literature Review on Ethical, Clinica, and Regulatory Considerations.

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A LITERATURE REVIEW

ABSTRACT

Dental nanorobotics is an emerging field with the potential to enhance oral healthcare through targeted, minimally invasive interventions. This review examines current evidence on patient acceptance, safety, and regulatory considerations of dental nanobots. Preclinical studies demonstrate applications in dentinal hypersensitivity management, root canal disinfection, biofilm removal, targeted drug delivery, and local anesthesia, employing magnetic guidance, swarm behavior, and biosensing. Clinical translation remains limited due to safety concerns, incomplete regulatory frameworks, and patient apprehension regarding device autonomy and long-term effects. Patient acceptance is influenced by trust, education, prior exposure, and cultural factors, while clinicians highlight the need for robust ethical and safety protocols. To bridge laboratory research and clinical practice, comprehensive preclinical evaluation, transparent patient engagement, and clear regulatory pathways are essential. Future studies should focus on patient-centered qualitative research, pilot clinical trials, and systematic safety validation to support ethical, effective, and acceptable integration of nanobots in dentistry.

Keywords: Mesenchymall Stem Cells; Drug Delivery; Headand Neck Cancer; Exosomes; Targeted.

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INTRODUCTION

Dental nanorobotics represents an emerging field integrating nanoscale engineering and robotic functions to address clinical challenges in oral health. Nanobots, or nanorobots, are autonomous or remotely controlled devices composed of nanoscale components (typically about 1-1000 nanometers, often 0.5-3 micrometers for medical capillary use) that integrate sensing, actuation, information processing, and payload modules to perform specific tasks in physical, chemical, or biological environments (Abiodun-Sloanke, 2014; Dasgupta, 2022). Proposed dental applications include dentinal hypersensitivity management, root canal disinfection, biofilm removal, targeted drug delivery, and local anesthesia. Patient acceptance and safety are critical for successful clinical implementation. This review aims to synthesize the literature regarding patient perceptions, ethical considerations, and safety profiles of dental nanobots, addressing the following questions: What is known about patient trust and willingness to accept nanobot-based dental treatments? What are the primary safety concerns and regulatory barriers?

REVIEW

Overview of Nanobots in Dentistry

Nanobots differ from general nanotechnology in scope, integration, autonomy, and function. While general nanotechnology encompasses manipulation and use of materials at the nanoscale (for example, nanoparticles, coatings, and sensors) without autonomous behavior (Abiodun-Sloanke, 2014; Giri, 2021), nanobots are engineered devices that combine propulsion, onboard computing, sensors, and payloads to perform active, targeted tasks (Dasgupta, 2022; Gutierrez, 2017). They can operate autonomously or under remote guidance, integrating materials and components from broader nanotechnology into robotic systems for tasks such as targeted theranostics, microsurgery, and continuous monitoring (Girir, 2021; Kasimoglu, 2020).

Current and emerging dental applications include management of dentinal

hypersensitivity through “CalBots,” which occlude exposed tubules using magnetically guided or functionalized carriers delivering biomineralizing agents (Abiodun-Sloanke, 2014; Malik, 2023). In endodontics, magnetically actuated helical silica/iron nanobots penetrate dentinal tubules up to 1-2 millimeters, using rotating or oscillating magnetic fields for targeted delivery and retrieval (Dasgupta, 2022). Localized hyperthermia and multimodal payloads (for example, antibiotics) enhance bacterial elimination, with operational doses averaging about 10^7 bots per canal and velocities around 3.6 micrometers per second. Nanobots can also disrupt biofilms beyond conventional irrigation limits, deliver targeted drugs to periodontal tissues, and potentially provide local anesthesia, although substantial safety validation is required (Dasgupta, 2022; Malik, 2023; Martins, 2021).

Mechanistically, nanobots rely on magnetic guidance (externally applied fields acting on helices or biohybrids), swarm behavior (chemotaxis, rheotaxis, phototaxis, or bioinspired algorithms), and integrated biosensing (chemical, thermal, optical, or neural sensors) to locate targets, deliver payloads, and confirm action via imaging or telemetry (Girir, 2021; Gutierrez, 2017; Nanobots, 2022; Nehru, 2022). Trade-offs include limited field penetration and equipment costs for magnetic guidance, biocompatibility concerns for chemical or self-propulsion, immune reactions with biohybrid systems, and the need for robust interfaces and low-power processing for biosensing (Giri, 2021; Nehru, 2022).

Clinical translation requires careful attention to retrievability or biodegradability, biocompatibility, biodistribution, procedural workflow, and regulatory compliance (Dasgupta, 2022; Malik, 2023; Silvera-Tawil, 2019). Effective strategies combine broad penetration via oscillating fields, sector-specific targeting with rotating fields, and synergistic antimicrobial action using triggered payload release, supported by rigorous preclinical evaluation (Dasgupta, 2022; Malik, 2023).

The main proposed applications of nanobots in dentistry are summarized in Table 1, highlighting the mechanisms, current status and barriers to the clinic.

Table 1 – Overview of Nanobot Applications in Dentistry

Clinical Application	Type of Nanobot / Material	Mechanism of Action	Current Stage (Evidence)	Main Barriers
Dentinal hypersensitivity	"CalBots" (magnetically guided or functionalized nanocarriers with biomineralizing agents)	Occlusion of dentinal tubules through targeted deposition of remineralizing compounds	Ex vivo studies and hypersensitivity models	Biocompatibility, controlled release, lack of clinical data
Root canal disinfection	Helical silica/iron magnetic nanobots	Penetration into dentinal tubules (up to 1–2 mm), localized hyperthermia and antibiotic release	In vitro and ex vivo studies (~10^7 bots per canal tested)	Toxicity, clearance, regulatory standardization
Biofilm disruption	Magnetic or biohybrid nanobots	Swarm navigation and mechanical/chemical disruption of biofilms	Laboratory studies (in vitro biofilms)	Validation in vivo/clinical setting, risk of off-target effects
Periodontal drug delivery / local anesthesia	Functional nanocarriers (silica, titania, biocompatible polymers)	Controlled drug release into periodontal tissues or pulp	Early experimental protocols	Risk of tissue retention, dual regulation (drug + device)
Preventive oral maintenance / monitoring	"Dentifrobots" and nanosensors	Continuous oral monitoring, preventive release of agents, orthodontic modulation	Conceptual / early prototyping	Patient acceptance, ethical concerns, data privacy

Patient Acceptance of Dental Nanobots

Public Perception of Nanotechnology in Medicine

Public attitudes toward nanotechnology in healthcare reflect cautious optimism. Nanorobotics are recognized for their potential in targeted therapeutics, diagnostics, minimally invasive procedures, and continuous monitoring, although

safety, biocompatibility, toxicity, ethical considerations, regulatory gaps, and costs remain critical concerns (Giri, 2021; Gutierrez, 2017; Nehru, 2022). Acceptance is higher when technologies augment rather than replace clinicians, and trust, education, and prior exposure enhance receptivity (Silvera-Tawil, 2019). Awareness of risks, particularly regarding data privacy, cybersecurity, and environmental impact, represents a significant barrier (Girir, 2021; Gutierrez, 2017). Stakeholders emphasize the need for rigorous evidence of safety, clinical efficacy, and longterm outcomes, as well as clear regulatory pathways before clinical implementation (Martins, 2021; Silvera-Tawil, 2019). Enthusiasm for advanced capabilities such as targeted cancer theranostics or brain/cloud interfaces is tempered by ethical concerns and practical limitations, including immune clearance and manufacturability, while biomimetic and biocompatible designs are preferred to reduce immune or toxic risks (Girir, 2021; Gutierrez, 2017; Martins, 2021; Nehru, 2022). Effective engagement, education, and transparent communication of risks and benefits are repeatedly recommended to enhance acceptance (Giri, 2021; Silvera-Tawil, 2019).

Age, education, culture, and trust in science further modulate perceptions. Older adults value assistive benefits but express concerns about privacy, safety, and potential job replacement, whereas younger individuals are generally more receptive to novel technologies but remain cautious (Silvera-Tawil, 2019; Tekinay, 2019). Higher technical or health literacy enhances appreciation of benefits and supports nuanced risk assessment, whereas lower literacy increases fear and demand for regulation (Giri, 2021; Silvera-Tawil, 2019; Scheufele, 2007). Clinicians and engineers similarly exhibit conditional acceptance when safety, efficacy, and workflow integration are demonstrated (Giri, 2021; Silvera-Tawil, 2019). Cultural context influences risk tolerance, consent, and willingness to adopt invasive Technologies (Nehru, 2022; Silvera-Tawil, 2019), while institutional trust strongly increases acceptance and lowers perceived risk (Giri, 2021; Silvera-Tawil, 2019). For neural interfaces, trust and ethical safeguards are decisive, particularly regarding privacy, consent, and oversight (Martins, 2021; Tekinay, 2019), and are discussed extensively in the context of brain-computer interfaces (Ienca, 2018). Adoption is highest when technologies are clinician-augmenting, evidence-backed, biocompatible, and embedded within trusted regulatory frameworks (Giri, 2021; Nehru, 2022; Silvera-Tawil, 2019).

Specific Data from Dentistry or Related Fields

Dental nanobots could enable dentifrobots for plaque control, dentin renaturalization, hypersensitivity treatment, targeted anesthesia, orthodontic repositioning, and continuous oral maintenance (Abiodun-Sloanke, 2014; Malik, 2023). Persistent bacteria within dentinal tubules contribute to root canal failures, as conventional irrigants penetrate only 20-800 micrometers depending on technique (NaOCl <20, ultrasound 160-330, laser 650-800) (Dasgupta, 2022). Magnetically actuated helical nanobots have been demonstrated to penetrate up to 1000-2000 micrometers, with oscillating fields enabling isotropic distribution and rotating fields allowing directional targeting and retrieval. These can be combined with hyperthermia or payload delivery for antibacterial therapy (Dasgupta, 2022). Safety, biocompatibility, and long-term effects of oral nanomaterials remain crucial considerations (Dasgupta, 2022; Gutierrez, 2017; Kasimoglu, 2020; Malik, 2023; Tekinay, 2019).

Additional applications include dentinal tubule occlusion to treat hypersensitivity, local anesthetic delivery via nanocarriers, orthodontic tissue modulation, and preventive monitoring with nanosensors (Abiodun-Sloanke, 2014; Malik, 2023; Tekinay, 2019). Experimental protocols suggest injection of about 10^7 nanobots per canal, actuated by rotating or oscillating magnetic fields, with hyperthermia providing localized bacterial reduction and retrieval achievable sector by sector (Dasgupta, 2022). Translation to clinical practice requires addressing toxicity, biodistribution, long-term fate, environmental impact, and regulatory compliance (Dasgupta, 2022; Gutierrez, 2017; Tekinay, 2019).

Barriers and Strategies to Improve Acceptance

Patient and clinician acceptance may be limited by fear of the unknown, lack of control, potential retention 2 of 4 of nanomaterials, and perceived loss of clinical authority (Dasgupta, 2022; Malik, 2023; Tekinay, 2019). Ethical, religious, and environmental concerns, alongside misconceptions fueled by media, further influence perception (Malik, 2023). Mitigation strategies include comprehensive patient education using multimedia, clear communication of benefits and risks, staged

deployment, clinician training, robust informed consent, and early engagement with cultural and ethical stakeholders (Abiodun-Solanke, 2014; Giri, 2021; Nanobots, 2022). Coordinated implementation of these strategies, alongside regulatory transparency and phased clinical introduction, is likely to foster higher acceptance across diverse patient populations while ensuring ethical, safe, and effective clinical translation.

Safety and Biocompatibility Concerns

Toxicity, Clearance, and Biocompatibility

Dental nanobots are primarily engineered from biocompatible materials such as silica and iron, with strategies for retrieval or controlled clearance. Magnetic helical nanobots accessing dentinal tubules have demonstrated guided ex vivo retrieval using rotating fields (Dasgupta, 2022). Design considerations emphasize biodegradation, self-deactivation, or active retrieval to reduce persistence (Giri, 2021; Nehru, 2022; Silvera-Tawil, 2019). Some dentifrobots are proposed to self-deactivate safely if ingested (Abiodun-Sloanke, 2014). Regulatory guidance requires defining end-of-life behaviors, including biodegradation kinetics, metabolic products, and excretion routes, all documented in toxicology packages (Giri, 2017; Martins, 2021). Preclinical programs should include cytotoxicity, immunogenicity, genotoxicity, local tissue histopathology, dose-range finding, incremental animal studies, phased human trials, and studies quantifying retention, systemic translocation, biodegradation products, and clearance routes (Giri, 2017; Martins, 2021; Nehru, 2022; Tekinay, 2019). Safety features should include fail-safe self-deactivation, controlled biodegradation, active retrieval strategies, and imaging or traceability markers compatible with clinical modalities (Dasgupta, 2022; Giri, 2021; Nehru, 2022). Clinical trial monitoring should ensure independent ethics review, layered informed consent detailing persistence or clearance uncertainties, and post-market surveillance plans (Malik, 2023; Martins, 2021).

Risks of Immune Response, Inflammation, and Off-Target Effects

Nanomaterials can provoke immune activation, pro-inflammatory responses, oxidative stress, or cytotoxicity depending on material, size, shape, and surface coating

(Giri, 2021; Malik, 2023; Tekinay, 2019). Biomimetic coatings, including cell-membrane and platelet or erythrocyte mimics, can reduce immune clearance and biofouling (Nehru, 2022; Silvera-Tawil, 2019). Nanobots may migrate systemically or cross biological barriers, emphasizing the need to measure distribution, persistence, and off-target effects while engineering behaviors to prevent uncontrolled migration (Giri, 2021; Nehru, 2022; Tekinay, 2019). Therapeutic modalities such as magnetic hyperthermia produce localized effects but require characterization of collateral tissue damage (Dasgupta, 2022). Although materials like silica and iron have prior biocompatibility data, full toxicology and long-term studies are necessary (Abiodun-Sloanke, 2014; Dasgupta, 2022).

Materials, Design, and Functional Considerations

Safe materials include iron oxide for magnetic control, silica for structural shells and drug loading, and titanium or titania for implant-compatible surfaces (Dasgupta, 2022; Malik, 2023; Tekinay, 2019). Coatings reduce immune clearance or biofouling, including PEGylation or antimicrobial layers, applied only after safety validation (Malik, 2023; Nanobots, 2022; Nehru, 2022; Tekinay, 2019). Magnetic control allows external navigation and retrieval; passive targeting optimizes size, shape, and surface ligands, and active targeting enables localized drug delivery via functionalization or stimuliresponsive release (Abiodun-Sloanke, 2014; Dasgupta, 2022; Malik, 2023; Tekinay, 2019). Propulsion prioritizes safe external actuation, avoiding toxic internal fuels (Dasgupta, 2022; Gutierrez, 2017; Malik, 2023; Nehru, 2022). Payloads should ensure tunable release kinetics and minimal collateral effects (Malik, 2023; Tekinay, 2019), while endof- life design ensures complete biodegradation or robust retrieval with controlled self-deactivation and metabolic fate profiles (Dasgupta, 2022; Giri, 2021; Nehru, 2022). Manufacturing must use scalable, GMP-compatible materials with validated sterilization, and regulatory submissions should include standardized risk, biodegradation, and environmental assessments (Giri, 2021; Martins, 2021; Tekinay, 2019).

Regulatory and Ethical Considerations

Current regulatory frameworks lack specific pathways for autonomous nanodevices, standardized testing, and long-term ecotoxicity protocols, and oversight is fragmented across medical device, biologic, environmental, and consumer regulators (Giri, 2021; Malik, 2023; Martins, 2021). Recommended guidance includes staged in vitro-animalhuman testing, standardized safety and environmental-fate studies, and independent review. Informed consent must convey device autonomy, fail-safe mechanisms, persistence or clearance uncertainties, and layered comprehension for patients or legal proxies (Abiodun-Sloanke, 2014; Giri, 2021; Malik, 2023; Martins, 2021). Long-term surveillance should monitor biodistribution, immune reactions, late-onset toxicity, and environmental release, with independent data oversight, unique device identification, adverse event reporting, and public disclosure (Dasgupta, 2022; Giri, 2021; Martins, 2021; Nehru, 2022). Tailored regulatory guidance should mandate standardized preclinical studies, layered informed consent, and robust trial and post-market surveillance (Giri, 2021; Malik, 2023; Martins, 2021).

Clinical Translation: Where Are We Now?

Preclinical studies on dental nanobots have demonstrated promising proof-of-concept results, primarily focusing on targeted cleaning of dentinal tubules, localized drug delivery, and manipulation of biofilms (Abiodun-Sloanke, 2014; Dasgupta, 2022). Most experimental work remains in vitro or ex vivo, with a few incremental animal studies investigating biodistribution, clearance, and safety profiles (Girir, 2021; Nehru, 2022). Technological readiness levels indicate that while individual components such as magnetic actuation, surface functionalization, and imaging markers are wellcharacterized, integrated systems suitable for human clinical use are still at early development stages (Martins, 2021). Significant barriers to translation include ensuring reproducible manufacturing at clinical standards, verifying long-term safety and immune compatibility, navigating incomplete regulatory frameworks for 3 of 4 autonomous nanodevices, and developing robust informed consent protocols that adequately convey novel risk profiles to patients (Giri, 2021; Malik, 2023).

DISCUSSION

Current evidence suggests that dental nanobots offer substantial theoretical benefits, including precise biofilm removal, targeted drug delivery, and enhanced oral health maintenance, but translation to clinical practice remains limited. Patient readiness is likely constrained by low awareness of the technology and potential concerns regarding safety, autonomy of devices, and long-term effects (Abiodun-Sloanke, 2014; Martins, 2021). While patients may expect rapid, minimally invasive improvements, real-world implementation is hindered by gaps in largescale studies, insufficient longitudinal safety data, and limited demonstration of autonomous nanobot operation in clinical settings (Giri, 2021). Future research should address these gaps through patient-centered qualitative studies to evaluate perceptions, pilot clinical trials with real nanobot applications under controlled conditions, and comprehensive safety testing protocols including toxicology and post-procedure surveillance (Dasgupta, 2022; Nehru, 2022). Integrating patient education, ethical considerations, and transparent reporting of outcomes will be critical to align expectations with feasible clinical advancements.

CONCLUSION

Dental nanobots represent a transformative potential in oral healthcare, yet their clinical translation remains in early stages. Current literature emphasizes that while technological components are advancing, comprehensive safety evaluation, regulatory guidance, and patient trust are essential for successful implementation. Addressing these factors through standardized preclinical studies, ethical frameworks, and patient engagement strategies will be crucial for integrating technological innovation with safe and acceptable applications in dentistry.

REFERENCES

Abiodun-Solanke I, Ajayi D, Arigbede A. Nanotechnology and its application in dentistry. Ann Med Health Sci Res. 2014;4:171-7. doi:10.4103/2141-9248.141951.

Dasgupta D, Peddi S, Saini DK, Ghosh A. Mobile nanobots for prevention of root canal treatment failure. Adv Healthc Mater. 2022;11:2200232. doi:10.1002/adhm.202200232

Giri G, Maddahi Y, Zareinia K. A brief review on challenges in design and development of nanorobots for medical applications. Appl Sci. 2021;11:10385. doi:10.3390/app112110385.

Gutierrez B, Bermúdez CV, Ureña YRC, et al. Nanobots: development and future. Int J Biosens Bioelectron. 2017;2:146-51. doi:10.15406/ijbsbe.2017.02.00037.

Kasimoglu Y, Tabakcilar D, Guclu ZA, Yamamoto-Nemoto S, Tuna EB, Ozen B, Ince G. Nanomaterials and nanorobotics in dentistry: a review. J Dent Indones. 2020;27:77-84. doi:10.14693/jdi.v27i2.1253.

Malik S, Muhammad K, Waheed Y. Emerging applications of nanotechnology in healthcare and medicine. Molecules. 2023;28:6624. doi:10.3390/molecules28186624.

Martins NRB, Angelica A, Chakravarthy K, Svidinenko Y, Boehm FJ, Opris I, Freitas RA. Human brain/cloud interface. In: Advances in Clinical Immunology, Medical Microbiology, COVID-19, and Big Data. Singapore: Jenny Stanford Publishing; 2021. doi:10.1201/9781003180432-26.

Nanobots: future and development. J Pharm Negat Results. 2022;2:1967-75. doi:10.47750/pnr.2022.13.S03.293.

Nehru S, Misra R, Bhaswant M. Multifaceted engineered biomimetic nanorobots toward cancer management. ACS Biomater Sci Eng. 2022;8:444-59. doi:10.1021/acsbiomaterials.1c01352.

Silvera-Tawil D. Robotics in healthcare: a survey. SN Comput Sci. 2024;5:189. doi:10.1007/s42979-023-02551-0.

Tekinay AB. Nanomaterials for regenerative medicine. In: Tekinay AB, editor. Nanomaterials for Regenerative Medicine. Cham: Springer; 2019. p.1-26. doi:10.1007/978-3-030-31202-2_1.

Scheufele DA, Corley EA, Dunwoody S, Shih TJ, Hillback E, Guston DH. Trust in scientists, media exposure, and the acceptance of nanotechnology risks. Nat Nanotechnol. 2007;2:732-6. doi:10.1038/nnano.2007.388.

Ienca M, Haselager P, Emanuel EJ. Brain-computer interfaces in clinical neuroscience: ethical challenges and future perspectives. Front Hum Neurosci. 2018;12:523. doi:10.3389/fnhum.2018.00523.