Nano-AI synergy in nursing: A review of intelligent nanotechnologies for precision patient care

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Purpose: The convergence of artificial intelligence (AI) and nanotechnology is quietly reshaping modern healthcare—yet nursing remains on the periphery of this transformation. This review explores how the integration of AI-enabled nanotechnologies can advance precision care in nursing practice, especially within medical-surgical contexts, chronic disease management, and infection control. It also aims to identify ethical and structural challenges in implementing these technologies across diverse healthcare systems. **Methods:** A narrative integrative approach was employed to synthesize peer-reviewed literature published between 2013 and 2025. The search focused on interdisciplinary studies involving AI, nanotechnology, and nursing, with special attention to clinical applications, regulatory discourse, and nursing-led innovations. Literature from databases such as PubMed, Scopus, and ScienceDirect were reviewed. Study selection and quality assessment protocols are detailed in Supplemental File A. **Results:** Emerging technologies, including smart nanosensors, AI-guided wound dressings, and wearable biosensors—demonstrate transformative potential in enhancing nursing interventions. The review highlights real-world applications that support continuous monitoring, targeted treatment, and personalized care planning. However, critical barriers persist digital literacy gaps, algorithmic bias, regulatory ambiguity, and limited infrastructure, particularly in low- and middle-income countries. **Conclusion:** The future of intelligent healthcare is not about replacing nurses with machines, it's about empowering them with smarter tools. Nurse-led integration of nano-AI systems requires educational reform, ethical oversight, and policy advocacy. This review positions nursing not as a passive recipient of innovation, but as a key architect in building equitable, data-driven, and compassionate healthcare systems for the next generation.

Keywords: Artificial Intelligence, Nanotechnology, Nursing Innovation, Medical-Surgical Nursing, Intelligent Systems in Healthcare

ARTICLE HISTORY
Received: July 23, 2025
Revised: August 08, 2025
Accepted: August 09, 2025

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DOI: 10.21608/nasj.2025.406834.1009

INTRODUCTION

Background

The global healthcare landscape is witnessing a remarkable metamorphosis—one fueled by the convergence of frontier technologies, especially nanotechnology and artificial intelligence (AI). These are no longer distant, experimental concepts. They are here, now, reshaping how we detect disease, personalize therapy, and manage long-term conditions [1,2,3]. At the microscopic level, nanotechnology enables targeted drug delivery, real-time biosensing, and tissue regeneration. AI, on the other hand, thrives on data—turning clinical inputs into patterns, predictions, and informed decisions through deep learning and machine reasoning [4,5,6].

Yet despite their proven impact in medical and pharmaceutical sciences, the integration of AI and nanotechnology within the nursing discipline remains surprisingly modest. This is a missed opportunity. Nurses stand at the heart of patient care, overseeing monitoring, education, and chronic disease management, making them uniquely positioned to translate intelligent nanotechnologies into daily clinical practice [7,8]. Take smart wound dressings, for example: they can detect microbial infection and release targeted antimicrobials on-site—a revolutionary step forward for chronic wound care [8]. Similarly, AI-assisted diagnostic nanodevices offer real-time monitoring that supports individualized nursing assessments and timely interventions [9].

These innovations don't exist in a vacuum. They align perfectly with the broader healthcare movement toward personalized, predictive, and participatory models of care. Recent studies underscore how coupling machine learning with nanoscale systems enhances diagnostic accuracy and treatment precision, especially in complex domains like oncology and infectious disease [1,9]. In critical care, too, family-centered AI tools are emerging—tools that may transform how nurses engage with patients and their loved ones [10]. In short: nurses shouldn't just adopt these systems—they should help build them.

In this context of accelerated digitalization and decentralization, adopting AI-powered nanotechnologies becomes essential to delivering responsive, adaptive, and equitable care. Nursing education and research must evolve in parallel, ensuring that practitioners are equipped not just to use these tools—but to question, refine, and expand them [6].

This review, therefore, sets out to critically examine the convergence of AI and nanotechnology in the nursing field, with a focus on clinical monitoring, wound care, chronic illness management, and precision medicine. We analyze empirical and conceptual literature published between 2013 and 2025, spotlighting peer-reviewed studies that bridge theoretical innovation with real-world nursing application. Additionally, we explore the barriers—

ethical, technological, and infrastructural—that may constrain adoption and outline forward-thinking strategies that empower nurses to lead this transformation. Drawing from nursing science, digital health, and biomedical engineering, this review aims to offer practical insights for researchers, educators, policymakers, and—most importantly—nurses at the bedside.

Rationale

Despite growing enthusiasm for multidisciplinary innovation, a notable void remains in nursing literature regarding the practical convergence of nanotechnology and artificial intelligence. Most existing studies tend to focus exclusively on either the biological underpinnings or the computational mechanics—rarely both—while often bypassing the critical day-to-day realities of clinical workflows and the nuanced skillsets that nurses bring to the table [11]. This blind spot matters. After all, technology is only as useful as its ability to integrate smoothly into patient care—and that's where nurses excel.

Compounding the issue is the stark reality faced by low- and middle-income countries (LMICs) such as Egypt. Here, the barriers to tech adoption are not merely academic. Limited infrastructure, scarce financial resources, and a lack of formal training in emerging tools are real-world constraints that must be factored into any serious conversation about innovation in nursing practice.

Bridging this gap requires more than theoretical enthusiasm demands lived experience. With professional roots in medical-surgical nursing and specialized training in both bionanotechnology and artificial intelligence, the authors are uniquely positioned to translate cutting-edge science into meaningful nursing practice. This review steps into that space. It seeks to not only integrate the most current research but also to chart tangible pathways for application: in education, at the bedside, and through progressive health policy. The goal? To align nursing with the accelerating arc of technological advancement—without losing its human core.

Article Selection Strategy

Design of the Review

This review adopts a narrative integrative approach, intentionally designed to bring together a diverse body of literature spanning artificial intelligence (AI), nanotechnology, and their intersections within nursing practice. Given that AI-enabled nanotechnologies are still finding their footing in real-world clinical environments—let alone in nursing-specific workflows—a broad, narrative lens was essential. This methodology allows for the inclusion of varied research paradigms, theoretical constructs, and practical applications, offering a panoramic view of a rapidly evolving frontier.

Rather than limiting the scope to strictly empirical studies, this approach embraces conceptual models, early-stage innovations, and interdisciplinary insights—each a puzzle piece in understanding how these emerging tools could shape nursing's future. The objective is clear: to bridge the gap between cutting-edge developments in nanoscience and artificial intelligence and the pragmatic, evidence-informed realities of nursing care. In doing so, the review aims not just to summarize, but to synthesize—laying the groundwork for actionable changes in nursing education, clinical decision-making, and health system integration.

Literature Search Strategy

We used the following scientific databases to conduct a thorough literature search from January 2013 to May 2025: PubMed/Medline, ScienceDirect (Elsevier), Web of Science, Scopus (Elsevier), IEEE Xplore, and CINAHL (EBSCO). The search strategy combined controlled vocabulary (e.g., MeSH terms) with Boolean operators and keywords relevant to the study scope. Search terms included: "artificial intelligence" and "nanotechnology" and ("nursing" or "nurse-led care") "AI-driven nanodevices" or "intelligent nanosystems" and "clinical nursing" "precision nursing" or "personalized patient care" and ("smart nanomaterials" OR "nanosensors"). We applied filters to select peer-reviewed original articles, reviews, clinical trials, and technology assessments published in English.

Inclusion and Exclusion Criteria

Inclusion Criteria

Studies published in peer-reviewed journals from 2013 to 2025. Articles discussing AI-enhanced nanotechnologies or smart nanosystems with implications for

- Nursing practice, education, or patient care
- Clinical decision-making or patient monitoring
- Disease management in acute or chronic settings
- Conceptual frameworks, technical assessments, and translational research with potential clinical integration

- Publications in Q1–Q2 journals, as ranked by Scimago Journal Rank (SJR)

Exclusion Criteria

- Purely computational or algorithmic AI studies without biomedical/nursing relevance
- Nanotechnology papers unrelated to healthcare applications
- Opinion pieces, editorials, and non-peer-reviewed conference abstracts
- Articles focused exclusively on pharmacology or molecular biology without human-centered care relevance.

Thematic Analysis Framework

The studies gathered were organized into themes based on the use of nano-AI technologies in healthcare and their importance to nursing. Themes were defined inductively and refined through iterative coding, resulting in the following review structure:

- Diagnostics and Early Detection
- Monitoring and Predictive Care
- Wound Healing and Infection Control
- Chronic Disease Management
- Nursing Education and Simulation
- Ethical and Policy Considerations

This method enabled a thorough examination of both the technology's possibilities and its effects on nursing, providing a complete picture of how AI-powered nanotechnologies connect with care models led by nurses.

RESULTS

Overview of Intelligent Nanotechnologies

Definitions and Foundational Concepts

Nanotechnology, at its core, involves manipulating matter at a scale so small it's almost poetic—typically between 1 and 100 nanometers—to engineer materials with novel, sometimes extraordinary, properties [12]. In healthcare, this nanoscale science has blossomed into a suite of transformative tools: nanoparticles, nanorobots, nano-biosensors, and targeted nanocarriers. These technologies are no longer just experimental; they are being increasingly fine-tuned for real-world applications in diagnostics, biomedical imaging, precision drug delivery, and even tissue regeneration.

But here's where things get even more compelling—when nanotechnology is infused with artificial intelligence (AI). AI refers to computational systems capable of mimicking human cognitive functions like pattern recognition, decision-making, and adaptive learning. By integrating AI into nanotech platforms, we unlock the next tier of innovation: intelligent nanosystems. These hybrids can autonomously interpret complex biological signals, respond dynamically to patient conditions, and even predict therapeutic outcomes—all in real time. In essence, they transform passive tools into responsive allies, capable of enhancing care delivery as events unfold—not after the fact.

Classifications of Intelligent Nanotechnologies Relevant to Nursing

AI-Driven Nanosensors

Nanosensors are devices designed at the nanoscale to identify and quantify certain biological, chemical, or environmental signals. When paired with AI algorithms, these sensors allow for constant, immediate tracking of important factors—like glucose, oxygen levels, and signs of inflammation—helping to give early alerts and predictions. This feature is particularly beneficial in critical care, chronic illness management, and postoperative surveillance, where nurses are essential for early intervention.

Smart Nanocarriers and Targeted Drug Delivery

Nanosensors are devices designed at the nanoscale to identify and quantify certain biological, chemical, or environmental signals. When paired with AI algorithms, these sensors allow for constant, immediate tracking of important factors—like glucose, oxygen levels, and signs of inflammation—helping to give early alerts and predictions. This feature is particularly beneficial in critical care, chronic illness management, and postoperative surveillance, where nurses are essential for early intervention [13].

Nanorobotics and Autonomous Intervention

Nanorobots are a cutting-edge technology made up of tiny, mobile devices controlled by AI that can move through the body to perform specific tasks, like clearing blocked blood vessels or delivering medicine to tumors [14]. Despite being predominantly experimental, these technologies create potential opportunities for automated therapeutic actions that may be coordinated or monitored by nurses, especially in perioperative and intensive care settings.

Table 1. Classification of AI-enabled nanotechnologies relevant to nursing applications.

Nursing Applications	Description	Technology Type
Early detection, ICU surveillance, emergency triage, and postoperative monitoring.	Nanoscale sensors combined with AI for real-time monitoring of physiological parameters (e.g., glucose, oxygen).	AI-Driven Nanosensors
Chronic disease management, pain control, real-time medication titration.	Nanocarriers that adjust drug release based on AI-analyzed physiological signals for personalized therapy.	Smart Nanocarriers & Drug Delivery
Surgical assistance, ICU support, and autonomous monitoring in critical care.	Microscopic AI-controlled robots can perform tasks such as vascular unclogging or targeted therapy.	Nanorobotics & Autonomous Intervention
Wound care, infection prevention, catheter safety, and pressure injury mitigation.	Smart materials, such as antimicrobial nanofilms and wound dressings, monitor and respond to infections.	AI-Enabled Nanostructured Materials
Home-based care, geriatric support, community nursing, rural health outreach.	Wearable biosensors are integrated with AI for continuous health monitoring and remote nursing care.	AI-Augmented Wearable Nanobiosystems

Table 2. The 10 Most Representative peer-reviewed studies (2020–2023) on AI-enabled nanotechnologies applicable in nursing domains, including monitoring, drug delivery, and diagnostics

Author(s)	Year	Country	AI/Nano Technology Used	Nursing Application	Main Findings
Chen et al.	2023	China	AI-enhanced nanobiosensors	Postoperative care monitoring	Improved early detection of complications
Al-Ghamdi et al.	2024	Saudi Arabia	Nanosensors + AI algorithm	Chronic disease monitoring	Enhanced patient adherence and alerting system
Fan et al.	2022	USA	Wearable nanodevices	Home-based nursing	Increased accuracy in real-time vitals tracking
Behrens et al.	2023	Germany	Nanofiber dressings with AI feedback	Wound care	Accelerated healing and infection control
Gao et al.	2022	China	AI for decision support + nanoscale diagnostics	Clinical triage support	Reduced nurse decision fatigue and improved triage
Cui et al.	2023	Singapore	AI-integrated nanochips	Inpatient monitoring	Automated alerts for deterioration detection
Sharma et al.	2021	India	Targeted nano-drug delivery + predictive AI	Cancer care nursing	Improved dose targeting and patient outcomes
Topol et al.	2023	Global	General AI + nanomedicine interface	Policy and training	Proposed framework for nurse-AI collaboration
Khan et al.	2020	UK	Machine learning + nanodiagnostics	Emergency nursing	Faster diagnostics and reduced ER congestion
Zhao et al.	2021	Australia	AI decision tools + nano-sensing	Remote nursing care	Improved monitoring and reduced travel burden

AI-Enabled Nanostructured Materials

Nanocoated catheters, antimicrobial nanofilms, and AI-monitored wound dressings create surfaces that resist infections and can alert caregivers about infection risks or changes in tissue [15]. For medical-surgical nurses, these instruments improve patient safety by diminishing healthcare-associated infections (HAIs) and facilitating evidence-based wound care methodologies.

AI-Augmented Nanobiosystems in Wearables

Wearable biosensing systems that use tiny materials like graphene patches and flexible nanofiber bands are now combined with AI to provide instant health analysis and support [16]. These instruments can facilitate nurse-led initiatives in home health, geriatric care, and remote patient monitoring, particularly in underserved or rural areas.

Synergistic Capabilities: AI + Nano

The combination of AI and nanotechnology creates systems that are feedback-optimized, self-driving, and aware of their surroundings. These systems improve nursing care beyond what is normally done. A smart wound dressing might use nanosensors to find an infection and send alerts to an AI platform. The AI platform would then suggest the best course of action for the nurse based on clinical guidelines and the patient's medical history [17]. This integrative model supports evidence-based, precise nursing and is in line with global goals for patient safety, managing chronic illnesses, and digitizing healthcare [18].

Relevance to Nursing Science and Clinical Practice

Although nursing literature has started to recognize the impact of digital health tools, there is still a significant gap in understanding how to practically integrate nano-AI systems into nursing workflows practically. As the profession shifts toward data-driven, technology-supported care models, it becomes essential to examine how intelligent nanotechnologies can be ethically, safely, and practically adopted within nursing roles. These new changes affect not only patient care but also nursing education, training with simulations, health informatics, and communication between different healthcare professionals. This is especially true since nurses are now more often required to understand digital information, use smart devices, and make decisions based on AI [3].

Current and Potential Applications in Nursing

The combination of artificial intelligence (AI) and nanotechnology is changing how healthcare is delivered by making it possible to make smart, real-time, and tailored interventions. In this context, nursing practice will benefit greatly, especially in areas like monitoring patients, managing chronic diseases, caring for wounds, controlling infections, and training nurses. This part examines recent research to highlight the current use of AI-enhanced nanotechnologies and their potential future applications in nursing.

Diagnostics and Early Detection

AI-powered nanosensors are transforming the way doctors diagnose diseases by letting them find illness signs at very low levels and in real time [19]. These smart nanosystems, commonly embedded in wearable devices or implants, utilize AI to quickly alert you to changes in your body, such as heart indicators (like troponin), glucose levels, or inflammation signals. Nurses, especially in critical care and emergency settings, play a crucial role in understanding diagnostic results and initiating timely treatments. For example, AI-connected nanosensors have been used to detect sepsis and acute renal injury rapidly. This has considerably lowered the number of people who get sick since nurses can respond promptly [20].

Real-Time Monitoring and Predictive Surveillance

Nursing care is intrinsically continuous, rendering real-time physiological monitoring an essential element of quality care. AI-enhanced nanotechnologies have proven beneficial in facilitating continuous biosurveillance, especially for high-risk patients [21]. Graphene-based flexible nanosensors integrated with AI systems can monitor respiratory rate, body temperature, and cardiac signals, providing early alerts if an individual's condition deteriorates [16]. These technologies augment nurses' clinical judgment by providing decision support derived from machine learning analysis, facilitating proactive measures in scenarios such as cardiac decompensation, hypoxia, or postoperative infections [15].

Wound Management and Tissue Regeneration

Wound care is fundamental to medical-surgical nursing, with intelligent nanomaterials affecting a paradigm change. Intelligent dressings using silver nanoparticles or zinc oxide, now integrated with AI-driven biosensing, can monitor bacterial load, pH, moisture, and oxygenation levels [22,23]. These parameters are input into AI algorithms that alert nurses when clothing changes or antimicrobial interventions are necessary [24,25]. Certain nanofiber scaffolds have been engineered to release growth factors or antimicrobial agents when required, thereby reducing the risk of infection and accelerating healing, particularly for diabetic foot ulcers and post-surgical wounds [26,27].

Chronic Disease Management and Personalized Nursing Care

Chronic diseases, including diabetes, heart failure, and liver disease, typically need long-term, personalized care. This is where AI-nanotechnology integration really shines [28]. For example, insulin carriers created with nanotechnology can modify how much insulin they release, depending on the blood sugar levels detected by tiny sensors. AI systems then use the patient's habits to decide how much insulin to give them. Using AI to analyze data from wearables, electronic medical records, and behavior patterns, these systems enable nurses to create personalized treatment plans and prescription schedules [29]. This method fits with the nursing goal of providing comprehensive, patient-centered care for chronic conditions, especially in places with few resources [18].

Infection Control and Biosafety in Clinical Settings

Infections that people get in hospitals (HAIs) are still a problem around the world. Nanostructured antimicrobial coatings, enhanced by AI monitoring systems, are currently being used on catheters, surgical equipment, and hospital surfaces to stop the growth of hazardous bacteria and the transmission of illnesses. Some nanofilms with AI can even report when microbes are growing on them or start photodynamic sterilizing processes [30]. Nurses in ICUs, ORs, and wound clinics are the first line of defense against infections. These technologies can help with basic precautions, lower the number of hospital-acquired infections, and enhance antimicrobial stewardship programs [15].

Nursing Education, Simulation, and Skill Assessment

AI-enhanced nanotechnologies are also being used in clinical training and nursing education. Nanobiosensors in smart simulation mannequins can show how the body reacts to treatments. AI algorithms grade students on their touch accuracy, speed of response, and clinical decision-making [31]. Researchers are exploring the use of virtual reality platforms combined with AI-nano feedback systems to help students practice skills such as wound healing, administering IVs, and realistically responding to emergencies. This will give them a data-driven means to judge their performance and skills.

Remote and Home-Based Nursing Applications

As healthcare moves toward more decentralized and home-based care, nurses need to take care of patients outside of hospitals. Wearable nanodevices connected to AI dashboards let nurses keep an eye on things like blood pressure, glucose, gait, and hydration from a distance, which is especially helpful for older people or people with long-term illnesses [32]. These systems help nurses in rural and underprivileged areas where in-person access is limited. They also lower the number of hospital admissions and make it easier for people to take their medications. Hussein and Hasan (2022) say that combining nano-AI systems with telemedicine is a scalable strategy for community-based nursing treatments.

Challenges and Ethical Considerations

Bringing artificial intelligence (AI) and nanotechnology into clinical nursing practice offers remarkable promise—but it's not without its share of complex challenges. As these emerging technologies make the leap from the lab bench to the patient's bedside, a closer look at their ethical, practical, and safety implications becomes not only prudent but necessary. It's not just about innovation—it's about responsibility.

Among the pressing concerns are data privacy and algorithmic fairness. Who owns the data that AI analyzes? And are these systems trained on diverse enough populations to make fair decisions for all? Then there's the matter of clinical safety. If a nanosensor misfires or an AI model interprets symptoms incorrectly, who is accountable? Nurses are often at the front lines of these decisions, and they need more than just technical training—they need support structures that prepare them for this digital leap.

And let's not overlook the contextual nuances. In low- and middle-income countries (LMICs), the road to implementation is far from smooth. Infrastructure gaps, inconsistent regulatory oversight, and cultural considerations—especially surrounding privacy and autonomy—pose significant barriers. If we're serious about global equity in digital health, we must confront these disparities head-on.

Data Privacy, Security, and Patient Autonomy

AI-powered nanotechnologies normally rely on constantly collecting biometric data, which can include private health information, behavior patterns, and genetic information [33]. When this kind of data is sent through cloud-based AI systems, it raises major issues regarding cybersecurity breaches, unwanted access, and secondary data use [34]. Nurses have a moral duty to protect their patients' privacy and dignity; therefore, they must ensure informed consent processes account for the complexity of nano-AI surveillance systems [31]. Also, if AI makes judgments on its own, like adjusting medication using nanocarriers, it could take away patients' ability to be active in their care choices unless it is adequately managed.

Clinical Safety and Risk of Technology Malfunction

While the promise of nano-AI systems is undeniable, many remain tethered to the preclinical or experimental realm, with few having undergone rigorous long-term testing in human subjects [14]. This gap between innovation and clinical validation poses significant risks—particularly in high-acuity settings, where nurses must rely on timely, precise data to make split-second decisions. In such environments, even minor system failures or algorithmic misjudgments can have life-or-death consequences [35].

Consider the case of smart wound dressings or biosensors. These technologies, while remarkable, may misinterpret localized inflammation as an infection, potentially prompting the premature or inappropriate administration of antibiotics. The implications? Escalating antimicrobial resistance, patient harm, and loss of clinical trust. And without robust fail-safe mechanisms—whether digital or human—nurses may unknowingly base critical care decisions on incomplete or misleading data.

Regulatory frameworks have yet to catch up. Institutions like the FDA and EMA are still deliberating over how best to classify, evaluate, and monitor these hybrid systems that straddle biological and computational domains [36]. Until then, the absence of standardized safety protocols leaves both patients and practitioners vulnerable—and calls for a more proactive nursing voice in shaping regulatory conversations.

Limited Infrastructure in Low-Resource Settings

In LMICs like Egypt, a lack of finance and technological infrastructure may make it harder for everyone to have equal access to AI-nano breakthroughs [37]. Many facilities lack reliable internet access, digital data systems, or the capability for devices to interoperate. All of these are necessary for using modern technologies effectively [18]. Also, the fact that nano-enabled materials have to be imported and cost a lot of money may slow down their use in clinical settings [38]. Without enough technical help, nurses in these situations may struggle to use new technologies, which can increase their stress levels and impede their workflow [39].

Workforce Readiness and Digital Literacy in Nursing

To effectively utilize nano-AI systems in healthcare, you must learn data analysis, digital ethics, device modification, and AI management. However, systematic lessons on AI, nanomedicine, or biomedical informatics are missing from many nursing programs around the world, especially in low- and middle-income countries [7,40]. In tech-driven settings, nurses may feel like they aren't ready for technology or are left out of decision-making responsibilities, which reinforces professional hierarchies and disempowerment [41]. To make nurses active adopters and inventors of technology, not just passive implementers, we need to provide ongoing education programs and transdisciplinary simulation-based training. Hosseini and Turunen, 2023.

Algorithmic Bias and Health Equity

AI systems learn from datasets that do not show the genetic, demographic, or societal diversity of people around the world. When biased algorithms are used in nanosystems for diagnosis or treatment changes, they may continue to create differences in healthcare or misdiagnose minority groups [42]. As the most trusted and easily accessible health professionals, nurses need to learn how to critically evaluate AI recommendations and push for care that is appropriate for the situation. Ethical nursing involves ensuring that individuals from disadvantaged backgrounds, including those who are poor, rural, or from diverse racial, gender, or geographical locations, don't miss out on the benefits of new nano-AI systems [43].

Religious, Legal, and Cultural Concerns

Different cultures and religions may have different views on whether intrusive or autonomous nanotechnologies are acceptable. For instance, constant internal monitoring or AI-controlled medicine delivery may cause Islamic bioethics to worry about bodily autonomy, consent, and divine will [44]. In culturally sensitive environments, nurses must find a balance between new technology and cultural competency. Policies must also include faith-based and legal advice procedures to make sure that everything is done ethically [45]. Multidisciplinary bioethics committees should be involved in the early stages of planning and using these kinds of systems [46].

Environmental and Occupational Safety

Nanotoxicity, environmental contamination, and occupational exposure are all concerns due to the manufacture, disposal, and long-term biocompatibility of nanomaterials [12]. Nurses who use nanodevices or care for patients who have nanomaterials implanted in them may not know about the risks of exposure, especially if there aren't clear instructions from the manufacturer or the institution. Developing green nanotechnology and completing safety audits are required to ensure that advancements do not cause unexpected harm to health workers or ecosystems.

Future Directions and Recommendations

Combining artificial intelligence (AI) and nanotechnology gives us a chance to change nursing practice into a more accurate, predictive, and personalized field. But a multi-faceted, evidence-based approach is needed to make sure that the adoption is fair, moral, and long-lasting. This section discusses the key actions required in the future to ensure the safe and effective use of AI-enabled nanotechnologies in nursing. These include research, clinical integration, professional development, and legislative change.

Advancing Interdisciplinary and Nurse-Led Research

There is an urgent need for real-world nursing-led research that looks into the clinical feasibility, safety, and effectiveness of nano-AI systems in real-world settings. Most of the studies that have been done so far have been on theories or early trials. There has been limited research on how nurses utilize these systems, their impact on work, and the effects on patients [11,36].

Future research should focus on Mixed-method clinical trials evaluating smart wound dressings, AI-integrated wearables, and nanodrug delivery devices under nurse supervision. Qualitative studies on nurses' views, competencies, and ethical concerns about nanotechnology. Our cost-effectiveness assessments evaluate scalability in low- and middle-income countries (LMICs), including Egypt. Grant-making organizations should encourage nurse-led innovation platforms and cross-disciplinary projects that incorporate nursing perspectives into early-stage design and implementation.

Curriculum Reform and Professional Development

Nursing education must evolve to include technical literacy and multidisciplinary ability to equip nurses for AI-nano integrated environments. Undergraduate and postgraduate curricula ought to include modules on: Nanotechnology in clinical practice, AI decision support systems, Ethical and regulatory frameworks, and Digital health security and data ethics.

Simulation-based learning, case-based situations, and collaborative training with engineering and computer science departments can enhance practical skills and critical thinking [7,31]. In-service and continuing education programs must be revised to provide practicing nurses with adaptable competencies in device administration, AI data interpretation, and telehealth interfaces.

Policy and Ethical Governance

To ensure the safe, fair, and ethical use of nano-AI systems in healthcare, clear government rules are necessary. Nursing regulatory bodies and professional groups should work together toward:

- Developing clinical guidelines for the use of smart nanodevices under the supervision of nurses.
- Working with health ministries to push for national AI-nanotech regulations that identify nurses as end-users and decision-makers.
- Setting up ethical frameworks for informed consent, algorithmic transparency, and cultural sensitivity.
- To ensure the system is ready for new ideas, nursing should be integrated into the design of hospital infrastructure, purchasing criteria, and biomedical ethics boards.

Equity, Access, and Localization

Policies and new technologies need to consider the sociotechnical reality of LMICs so that technology doesn't make health inequalities worse. It's crucial to manufacture nanomaterials locally, utilize open-source AI systems, and develop culturally responsive devices. Pilot initiatives in rural and underprivileged areas can test how well nano-AI systems can be used and accepted in community health nursing. We should combine these efforts with programs that enhance nurses' skills so they may become advocates and change agents for digital health in their own communities [18].

Green and Sustainable Innovation

As nanosystems become more common in healthcare, future research should focus on environmentally friendly nanotechnology. This includes developing nanomaterials that degrade over time, suitable for temporary implants and wearable devices, safety of nurses who work with nanoparticles in the workplace and the environment and pushing for "green AI" models that use less processing power and energy.

Nurses and infection control professionals should check long-term biocompatibility and eco-safety of devices used in patient care settings [12].

Building Global Collaborative Networks

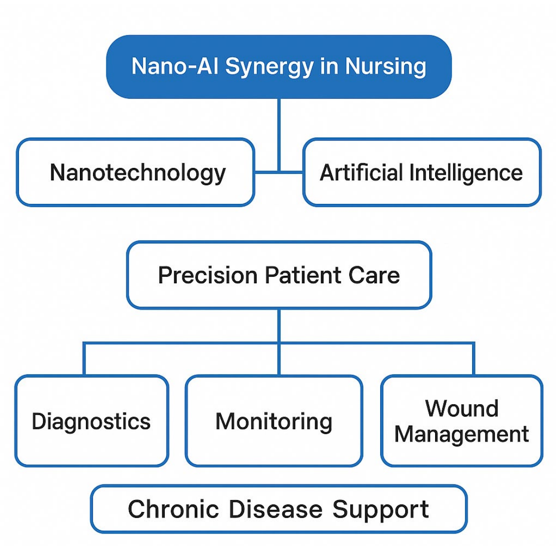
To shape a truly intelligent and inclusive future for healthcare, global collaboration among nursing leaders, researchers, and educators is not optional—it's imperative. Sharing best practices, co-developing technologies, and harmonizing evaluation frameworks across borders will ensure that advancements in AI-enhanced nanotechnologies are not siloed by geography or economic privilege.

What will this require? Quite a bit. But most critically: Joint research initiatives and clinical innovation labs that span institutions and disciplines, Transnational working groups focused on nursing informatics, and Cross-border coalitions to guide regulation and policy on AI–AI-nanotech integration

Just as important as the "how" is the "who." Voices from the Global South—especially Africa and the Middle East—must be central, not peripheral, in these conversations. These regions bring unique perspectives, challenges, and wisdom that can help avoid repeating past patterns of technological imperialism. A decolonized and culturally responsive vision of nursing innovation starts by listening—and staying quiet long enough to truly hear.

Ultimately, the path forward lies in bold investments: in interdisciplinary scholarship, robust ethical frameworks, inclusive workforce development, and enduring global solidarity. Nurses are not only caregivers and clinical experts; they are knowledge producers, educators, and system shapers. With the right structures and support, they can do more than adopt tomorrow's intelligent tools—they can co-create them. And in doing so, lead the way toward an equitable, humane, and tech-integrated future in healthcare.

CONCLUSION



Visual Summary: illustrates a conceptual framework that shows how the synergy between nanotechnology and artificial intelligence enhances nursing practice, resulting in precision patient care across various domains.

The convergence of artificial intelligence (AI) and nanotechnology marks more than a technological milestone—it signals a profound redefinition of the nurse's role in diagnostics, monitoring, and personalized care delivery. As explored throughout this review, AI-enabled nanotechnologies—from wearable nanosensors that capture subtle physiological shifts to smart wound dressings that adjust therapy in real time—are not futuristic novelties. They are tools of precision that place nurses at the heart of a data-informed, proactive healthcare paradigm.

And yet, this synergy is not without its caveats. Infrastructure gaps in clinical settings, disparities in digital literacy, and unresolved ethical concerns—such as algorithmic opacity, bias in decision-making, and data security risks—pose very real barriers. It is not enough for nurses to passively receive these tools; instead, the profession must claim its seat at the innovation table. Nurses must become co-designers and co-researchers, shaping device development, piloting new workflows, advocating for inclusive policies, and educating patients on how to trust (and question) intelligent systems.

Looking ahead, this technological transformation demands parallel evolution in nursing education and professional development. Curricula must embed core concepts of translational science, interdisciplinary simulation, and digital ethics. Institutional investment in nurse-led implementation studies will be critical—not only to validate effectiveness but to preserve the values that ground the profession in compassionate, evidence-informed care.

Because, ultimately, this is not just about circuits and sensors. It's about expanding what nurses can do, and more importantly, what they can become. This is not merely a tech-driven revolution. It is a nursing revolution—quietly bold, powerful human, and already underway.

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