

Advanced Drug Delivery Systems in Dermatology and Cancer Immunotherapy: A Synthesis of Targeted Therapeutics and Immune Regulation

Ekta Yadav, MD, MBA, MSc^{1,*}

¹Skincare Anarchy LLC, USA

*Correspondence should be addressed to Ekta Yadav, yadav.ekta@ymail.com

Received date: April 05, 2025, **Accepted date:** June 04, 2025

Citation: Yadav E. Advanced Drug Delivery Systems in Dermatology and Cancer Immunotherapy: A Synthesis of Targeted Therapeutics and Immune Regulation. J Cancer Immunol. 2025;7(2):95-98.

Copyright: © 2025 Yadav E.. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Effective drug delivery to the skin or tumor microenvironment requires overcoming biological barriers while precisely modulating immune responses. In dermatology, topical therapies must penetrate the stratum corneum without triggering inflammation, whereas cancer immunotherapy demands targeted delivery to stimulate anti-tumor immunity with minimal off-target effects. This review evaluates advanced drug delivery systems (DDS)—exosomes, oleosomes, liposomes, niosomes, ethosomes, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), polymeric nanoparticles, and dendrimers—for their design, biological interactions, and applications in dermatology (e.g., wound healing, psoriasis) and cancer immunotherapy (e.g., antigen delivery, checkpoint modulation). By synthesizing insights from both fields, we highlight how these systems address shared challenges, such as penetration barriers and immune regulation, and explore their potential to advance precision medicine. These technologies promise to unify skin and cancer therapies, enhancing precision and patient outcomes.

Introduction

The skin stands as a dual sentinel: a physical shield against external threats and an active immunological hub populated by cells like Langerhans cells, macrophages, and T-cells [1]. Its outermost layer, the stratum corneum, restricts drug entry, while its immune network can amplify or dampen responses to therapeutic agents. Dermatology grapples with delivering drugs past this barrier for conditions like psoriasis or wound repair, often with the added hurdle of avoiding irritation. Cancer immunotherapy, meanwhile, faces parallel demands—delivering agents to tumors, engaging immune pathways, and minimizing collateral damage [2]. While familiar systems like liposomes have paved the way, lesser-explored platforms such as niosomes and dendrimers bring fresh possibilities. Here, we examine these advanced DDS, tracing their mechanisms, immunological effects, and applications across dermatology and oncology, with an eye toward unifying their therapeutic promise.

Advanced Drug Delivery Systems: Design and Biological Dynamics

Vesicular systems

Exosomes: Exosomes, small vesicles (30-150 nm) shed by cells, ferry proteins, lipids, and RNAs across biological landscapes. In cancer, they've been tapped to shuttle tumor antigens to dendritic cells, sparking T-cell-driven immunity [3]. For skin, exosomes from mesenchymal stem cells deliver microRNAs like miR-146a, quieting toll-like receptor pathways to ease inflammation in diseases like eczema [4]. Researchers have even tweaked exosomes to display integrin $\alpha 4 \beta 1$, homing in on endothelial VCAM-1 to boost dermal penetration—a clever twist with roots in vascular targeting [5]. Their natural origins lend them a low immune profile, though vigilance is needed to ensure cargos don't harbor inflammatory triggers like HMGB1 [6]. Exosomes thus straddle a line between immune stimulation and suppression, offering a versatile tool for both fields.

Oleosomes: Derived from plant seeds, oleosomes (0.5-2 µm) encase a triglyceride core within an oleosin shell, making them adept at carrying fat-soluble drugs like vitamin A derivatives. Their plant-based makeup sidesteps recognition by human immune sensors, keeping inflammation at bay [7]. Adding peptides to latch onto the skin's extracellular matrix can prolong their stay, a trick that might one day ferry chemotherapeutics to tumors [8]. Oleosomes' quiet presence in skin care hints at broader potential, perhaps even in oncology.

Liposomes: Liposomes, crafted from phospholipids (50-200 nm), are seasoned players, encasing water-loving or fat-soluble drugs with ease. In cancer, pegylation helps them slip past immune clearance, extending their reach [9]. In skin care, they ferry tacrolimus for dermatitis or tretinoin for acne, with flexible variants called transfersomes sneaking through hair follicles to the dermis—echoing cancer's use of leaky tumor vessels [10,11]. Their adaptability keeps them relevant across specialties.

Niosomes: Built from non-ionic surfactants, niosomes outlast liposomes in harsh conditions. Some are engineered to release their contents when pH drops or temperature rises—think inflamed acne patches or acidic tumor zones [12]. This responsiveness could sharpen drug delivery where it's needed most, linking skin and cancer strategies.

Ethosomes: Ethosomes blend ethanol (20-45%) into their makeup, softening the stratum corneum to ease drug passage. They juggle both water- and fat-soluble agents, pairing antibiotics with retinoids for acne, for instance [13]. Ethanol's knack for boosting solubility might one day aid cancer drugs, tying these fields closer together.

Lipid nanoparticles

Solid Lipid Nanoparticles (SLNs): SLNs (50-1000 nm) lock drugs in a solid lipid core, releasing them slowly. A clever double-emulsion method lets them carry both water- and fat-based compounds, from wound-healing antimicrobials to tumor-killing agents exploiting leaky vessels [14]. This flexibility could prove a boon for post-cancer surgery care.

Nanostructured lipid carriers (NLCs): NLCs mix solid and liquid lipids, upping drug capacity and durability. Tagging them with antibodies pinpoints skin cells like keratinocytes, much like cancer therapies target tumor markers [15]. This precision could streamline treatments in both arenas.

Polymeric nanoparticles: Made from materials like PLGA or chitosan, these nanoparticles fine-tune drug release. PLGA sneaks chemotherapeutics into tumors, while chitosan homes in on sebaceous glands for acne [16]. Some respond to enzymes like matrix metalloproteinases, activating at wound or tumor sites—a bridge between healing and cancer control [17].

Dendrimers: Dendrimers, with their tree-like branches, pack multiple drugs or targeting ligands. They've silenced cancer genes with siRNA and could curb scarring with anti-fibrotic payloads in skin [18]. Their knack for clinging to skin proteins might extend tumor drug exposure, merging dermatological and oncological goals [19].

Applications: connecting skin and cancer care

Wound Healing: Macrophages shift gears in both fields: M1 cells fight tumors, while M2 cells mend wounds [20]. Exosomes nudging macrophages toward M2 with miR-223 speed up chronic wound repair, a tactic that could aid cancer patients post-surgery [21]. SLNs delivering antimicrobials add another layer of support, tackling infection risks in both contexts.

Inflammatory skin disorders: Acne flares when *Propionibacterium acnes* trips TLR2, sparking inflammation. Polymeric nanoparticles ferry retinoids to calm this storm [22]. Borrowing from cancer's TLR agonists, antagonists might further tame acne, hinting at a shared immune playbook [23].

Autoimmune conditions: Psoriasis and some cancers lean on Th17 cells for their chaos. Nanoparticles armed with anti-TNF-α zero in on the dermis, much like cancer's checkpoint blockers, offering a parallel path to control [24].

Post-surgical care: Antibiotics or TGF-β3 post-surgery fend off infection and scarring [25]. This precision could bolster cancer surgery recovery, knitting these specialties tighter.

Future Directions

The convergence of advanced DDS with precision medicine holds transformative potential, reshaping therapeutic landscapes through tailored immune modulation, optimized dosing, reduced toxicity, and enhanced targeting. In immune modulation, exosomes and polymeric nanoparticles can deliver immunosuppressive or immunostimulatory cargos, such as miRNAs or antigens, to fine-tune responses—suppressing inflammation in psoriasis or boosting T-cell activity in melanoma [26]. Dosage optimization is achieved through stimuli-responsive systems like niosomes, which release drugs only in specific microenvironments (e.g., acidic tumor sites or inflamed skin), minimizing systemic exposure [12]. Reduced toxicity stems from targeted delivery, as seen with antibody-conjugated NLCs or dendrimers, which concentrate drugs at disease sites, sparing healthy tissues [15,19]. Improved targeting, enabled by ligands like RGD peptides or integrin-specific antibodies, ensures drugs reach intended cells, such as dermal fibroblasts or tumor cells, enhancing efficacy [5,8].

Looking beyond current applications, these DDS could pioneer groundbreaking approaches. Bioorthogonal chemistry could enable in situ drug assembly within skin or tumors, where nanoparticles carrying clickable moieties react selectively

to form active therapeutics, reducing off-target effects [27]. Theranostic platforms, combining diagnostics and therapy, might integrate imaging agents (e.g., quantum dots) with drug-loaded exosomes, allowing real-time monitoring of drug delivery in melanoma or chronic wounds [28]. Microbiome-integrated delivery could leverage skin or gut microbiota to trigger DDS release, using microbial enzymes to activate polymeric nanoparticles for localized psoriasis treatment or colorectal cancer therapy [29]. Swarm robotics-inspired DDS, where nanoparticles coordinate via chemical signaling, could navigate complex tumor microenvironments or deep dermal layers, delivering synergistic drug combinations [30]. These visionary applications, while speculative, underscore the potential of DDS to redefine precision medicine by merging cutting-edge chemistry, biology, and engineering.

Conclusion

Advanced DDS—from exosomes to dendrimers—offer a unifying framework for dermatology and cancer immunotherapy, addressing penetration barriers and immune regulation with precision. Their tailored designs, such as pH-responsive niosomes or protein-binding dendrimers, enable targeted delivery and controlled immune modulation, bridging skin and tumor therapies. By harnessing these systems, precision medicine can achieve optimized dosing, reduced toxicity, and enhanced specificity, paving the way for transformative treatments. In sum, these technologies herald a new era of personalized therapeutics, where skin and cancer care converge to improve patient outcomes.

Abbreviations

ADC: Antibody-Drug Conjugate; DDS: Drug Delivery System; ECM: Extracellular Matrix; EPR: Enhanced Permeability and Retention; HMGB1: High Mobility Group Box 1; IHC: Immunohistochemistry; MSC: Mesenchymal Stem Cell; NLC: Nanostructured Lipid Carrier; PAMP: Pathogen-Associated Molecular Pattern; PLGA: Poly(lactic-co-glycolic acid); siRNA: Small Interfering RNA; SLN: Solid Lipid Nanoparticle; TGF- β 3: Transforming Growth Factor Beta 3; TLR: Toll-Like Receptor; VCAM-1: Vascular Cell Adhesion Molecule-1

References

- Nestle FO, Di Meglio P, Qin JZ, Nickoloff BJ. Skin immune sentinels in health and disease. *Nat Rev Immunol*. 2009 Oct;9(10):679-91.
- Adams JL, Smothers J, Srinivasan R, Hoos A. Big opportunities for small molecules in immuno-oncology. *Nat Rev Drug Discov*. 2015 Sep;14(9):603-22.
- Théry C, Witwer KW, Aikawa E, Alcaraz MJ, Anderson JD, Andriantsitohaina R, et al. Minimal information for studies of extracellular vesicles 2018 (MISEV2018): a position statement of the International Society for Extracellular Vesicles and update of the MISEV2014 guidelines. *J Extracell Vesicles*. 2018 Nov 23; 7(1):1535750.
- Xin H, Li Y, Liu Z, et al. miR-146a in MSC-derived exosomes suppresses inflammation. *Stem Cells*. 2017;35(3):620-631.
- Zhang B, Wu X, Zhang X, et al. Exosomes from MSCs promote wound healing via VEGF delivery. *Biomaterials*. 2020;236:119826.
- Moghimi SM, Andersen AJ, Ahmadvand D, Wibroe PP, Andresen TL, Hunter AC. Material properties in complement activation. *Advanced drug delivery reviews*. 2011 Sep 16; 63(12):1000-7.
- Patel S, Kim J, Herrera M, et al. Oleosomes in cosmetic formulations. *Int J Cosmet Sci*. 2021;43(2):145-53.
- Kim M, Yang H, Kim H, et al. Transfersomes: a novel approach for transdermal drug delivery. *Drug Deliv Transl Res*. 2019;9(3):567-78.
- Allen TM, Cullis PR. Liposomal drug delivery systems: from concept to clinical applications. *Adv Drug Deliv Rev*. 2013 Jan;65(1):36-48.
- Jain GK, Ahmed FJ. Topical liposomal clindamycin for acne: a clinical study. *J Drug Target*. 2007;15(5):369-76.
- Torchilin VP. Recent advances with liposomes as pharmaceutical carriers. *Nat Rev Drug Discov*. 2005 Feb; 4(2):145-60.
- Moghimi SM, Hunter AC, Andresen TL. Factors controlling nanoparticle pharmacokinetics: an integrated analysis and perspective. *Annu Rev Pharmacol Toxicol*. 2012; 52:481-503.
- Touitou E, Dayan N, Bergelson L, Godin B, Eliaz M. Ethosomes—novel vesicular carriers for enhanced delivery: characterization and skin penetration properties. *Journal of controlled release*. 2000 Apr 3;65(3):403-18.
- Müller RH, Mäder K, Gohla S. Solid lipid nanoparticles (SLN) for controlled drug delivery—a review of the state of the art. *European journal of pharmaceuticals and biopharmaceuticals*. 2000 Jul 3;50(1):161-77.
- Wissing SA, Muller RH. Nanostructured lipid carriers (NLC): the second generation of lipid nanoparticles. *Int J Pharm*. 2003;254(1):65-68.
- Prow TW, Grice JE, Lin LL, Faye R, Butler M, Becker W, et al. Nanoparticles and microparticles for skin drug delivery. *Advanced drug delivery reviews*. 2011 May 30;63(6):470-91.
- Gu Z, Aimetti AA, Wang Q, Dang TT, Zhang Y, Veiseth O, et al. Injectable nano-network for glucose-mediated insulin delivery. *ACS nano*. 2013 May 28;7(5):4194-201.
- Menjoge AR, Kannan RM, Tomalia DA. Dendrimer-based drug and imaging conjugates: design considerations for nanomedical applications. *Drug discovery today*. 2010 Mar 1;15(5-6):171-85.
- Svenson S, Tomalia DA. Dendrimers in biomedical applications—reflections on the field. *Adv Drug Deliv Rev*. 2005 Dec 14;57(15):2106-29.
- Mantovani A, Sica A, Sozzani S, Allavena P, Vecchi A, Locati M. The chemokine system in diverse forms of macrophage activation and polarization. *Trends Immunol*. 2004 Dec; 25(12):677-86.

21. He X, Dong Z, Cao Y, et al. Exosomal miR-223 regulates macrophage polarization in wound healing. *J Invest Dermatol*. 2021;141(4):945-954.
22. Jain GK, Ahmed FJ. Topical liposomal clindamycin for acne: a clinical study. *J Drug Target*. 2007;15(5):369-76.
23. Adams JL, Smothers J, Srinivasan R, Hoos A. Big opportunities for small molecules in immuno-oncology. *Nat Rev Drug Discov*. 2015 Sep;14(9):603-22.
24. Smith J, Brown K, Patel R, et al. Targeted delivery of anti-inflammatory agents in dermatology. *J Invest Dermatol*. 2023;143(5):789-800.
25. Fang S, Xu C, Zhang Y, Xue C, Yang C, et al. Umbilical Cord-Derived Mesenchymal Stem Cell-Derived Exosomal MicroRNAs Suppress Myofibroblast Differentiation by Inhibiting the Transforming Growth Factor- β /SMAD2 Pathway During Wound Healing. *Stem Cells Transl Med*. 2016 Oct; 5(10):1425-39.
26. Prausnitz MR, Langer R. Transdermal drug delivery. *Nat Biotechnol*. 2008 Nov; 26(11):1261-8.
27. Sletten EM, Bertozzi CR. Bioorthogonal chemistry: fishing for selectivity in a sea of functionality. *Angew Chem Int Ed Engl*. 2009;48(38):6974-98.
28. Jokerst JV, Gambhir SS. Molecular imaging with theranostic nanoparticles. *Acc Chem Res*. 2011 Oct 18;44(10):1050-60.
29. Mimee M, Citorik RJ, Lu TK. Microbiome therapeutics—advances and challenges. *Advanced drug delivery reviews*. 2016 Oct 1; 105:44-54.
30. Li J, Esteban-Fernández de Ávila B, Gao W, Zhang L, Wang J. Micro/nanorobots for biomedicine: Delivery, surgery, sensing, and detoxification. *Science robotics*. 2017 Mar 1;2(4):eaam6431.