INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

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Review Paper

Design and Development of Transdermal Patches for Controlled Drug Delivery.

Dhruv Shudra*, Premkumar Devadiya

School of Pharmacy, Rai University, Ahmedabad, Gujarat

ARTICLE INFO

Published: 20 Nov 2025
Keywords:
Transdermal drug delivery, controlled release, polymers, permeation enhancers, skin barrier, formulation design, evaluation
DOI:
10.5281/zenodo.17662975

ABSTRACT

The transdermal route of administration has become one of the most novel and effective methods for controlled drug delivery. Transdermal patches present many advantages when compared to conventional dosage forms, which include steering clear of first-pass metabolism, offering sustained plasma concentrations, decreasing dosing frequency, and enhancing patient compliance. Transdermal systems apply therapeutic agents across the skin directly into the systemic circulation, in a controllable and predictable manner. The formulation design of transdermal patches considers multiple factors, such as drug physicochemical properties, polymer matrix, permeation enhancers, adhesive, and backing layers. This review will discuss a range of topics including, the principles of transdermal drug delivery systems, the formulation design of transdermal patches, mechanism of drug permeation of transdermal patches, evaluation parameters, challenges, and future prospects in transdermal drug delivery systems. The transdermal patches represent a new depth of versatility as polymer technology and nanotechnology continues to develop, and become a unique platform for effective and controlled delivery of both small and large therapeutic agents through transdermal patches.

INTRODUCTION

Over the past few decades, there has been considerable interest in drug delivery through the skin in order to achieve systemic drug effects. The skin is the largest organ of the body and provides a favourable surface for non-invasive drug delivery. Transdermal drug delivery systems (TDDS) are formulated to deliver a drug to systemic circulation at a controlled rate through the skin layers.

Oral, parenteral and topical routes of administration can be associated with disadvantages including first-pass hepatic drug metabolism, gastrointestinal degradation of the drug, or poor patient compliance with parenteral administration methods. Thus, transdermal drug

***Corresponding Author:** Dhruv Shudra
Address: *School of Pharmacy, Rai University, Ahmedabad, Gujarat*
Email ✉: Dhruvshudra958@gmail.com
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

delivery systems provide a solution to many of those traditional methods of delivery, since they can continuously deliver a drug over long periods of time.

The first commercially available transdermal patch (Transdermal Scop - scopolamine) was approved in 1979 for the treatment of motion sickness. Since then, numerous transdermal delivery systems such as nitro-glycerine, nicotine, fentanyl and estradiol patches have been developed and successfully marketed. New exciting technologies in the development of polymers, microneedles, and iontophoretic delivery systems enhance the ability of TDDS to deliver drugs more effectively and expand the range of use.

1.2 Advantages of Transdermal Drug Delivery

Transdermal patches provide a number of pharmacokinetic and patient focused advantages when compared to conventional dosage forms, including:

- **Bypassing first-pass metabolism** — resulting in greater bioavailability.
- **Continuous and controlled release of drug delivery** — resulting in maintained plasma concentration.
- **Non-invasive and convenient** — leading to improved patient compliance.
- **Reduced dosing frequency** — particularly advantageous in chronic conditions.
- **Easily discontinued therapy** — as taking off the patch immediately stops drug delivery.
- **Reduced gastrointestinal adverse effects** — as it bypasses irritation of the gastrointestinal tract.
- **Enhanced therapeutic effect** — as there is constant drug infusion.

1.3 Limitations and Challenges

TDDs have some limitations even though they have many advantages:

- The stratum corneum is an important barrier to skin permeation.
- Only drugs that have appropriate lipophilicity and molecular weight (< 500 Da) will effectively permeate the skin.
- Skin irritation or sensitization can occur due to enhancers or adhesive.
- Limited drug dose capacity (usually ≤10 mg/day).
- Inter- and intra-individual variability affected by skin conditions, hydration and temperature.

1.4 Structure of The Skin and Mechanism of Drug Permeation

The skin is composed of three primary layers:

1. Epidermis (outer layer)
2. Dermis (middle with vascularization)
3. Hypodermis (subcutaneous fatty layer)

The stratum corneum is the outermost layer of the epidermis and is responsible for controlling the rate of drug penetration. The stratum corneum is made of keratinized, dead cells that are enclosed in a lipid matrix that resembles a “brick-and-mortar” structure.

Mechanism of permeability:

Drugs penetrate the skin by:

- **Transcellular:** through corneocytes.
- **Intercellular:** between corneocytes through lipids.
- **Appendageal:** through sweat glands or hair follicles (minor route).

Penetration is defined as:

- Diffusion through the stratum corneum
- Partitioning into the deeper layers of the epidermis
- Absorption into systemic circulation through the microcirculation in the dermis

The rate of permeability (dQ/dt) can be determined by Fick's first law of diffusion: J is the flux, D is the diffusion coefficient, K is the partition coefficient, ΔC is the concentration gradient, and h is the thickness of the membrane.

1.5 Ideal Characteristics of Drugs for Transdermal Delivery

An optimal drug candidate for transdermal delivery system (TDDS) should have:

- Molecular weight <500 Daltons
- Sufficient lipid and water solubility
- Log P value between 1-4
- Dosage <10 mg/day
- Low melting point (<200 degrees Celsius)
- Non-irritant/non-sensitizing property
- Short biological half-life that necessitates controlled release.

Examples of drug candidates are clonidine; nitro-glycerine; oestradiol; nicotine; and fentanyl.

1.6 Types of Transdermal Patches

Transdermal patches can be categorized as follows:

1.6.1 Reservoir-Type Patch:

The drug is contained in a reservoir compartment situated between a backing layer and a rate-controlling membrane. This type of drug delivery enables the use of zero-order release kinetics. An example of this is the Nitro-Dur patch (Nitro-glycerine).

1.6.2 Matrix-Type Patch:

The drug is dispersed in a polymer matrix, which acts as the drug control layer. While simpler in design, this type of patch is flexible, but a more multidisciplinary approach may be warranted. Estraderm patch (Oestradiol) serves as an example of matrix-type patches.

1.6.3 Drug-in-Adhesive System:

An adhesive layer containing the drug is used. This type of patch is thinner and has a more favourable wear comfort. Nicotine patches (NicoDerm CQ) can be considered an example of Drug-in-Adhesive.

1.6.4 Micro-Reservoir System:

The patch consists of drug suspension dispersed in microscopic polymeric reservoirs. This patch type is a drug delivery system that could offer controlled release and better stability.

1.7 Components of A Transdermal Patch

1. **Polymeric matrix:** Regulates drug release (e.g., PVP, Eudragit, HPMC, EC).
2. **Drug:** Active pharmaceutical ingredient with appropriate skin permeation.
3. **Permeation enhancers:** Aid in diffusion (e.g., DMSO, oleic acid, menthol).
4. **Adhesive:** Provides skin adhesion (e.g., polyisobutylene, silicone).
5. **Backing layer:** Provides protection (e.g., polyester, polyethylene film).
6. **Release liner:** Removed before used (e.g., Teflon coated sheets).
7. **Plasticizers:** Increase flexibility (e.g., PEG, DBP).

2. FORMULATION AND EVALUATION

2.1 Formulation Design and Development

The process consists of:

- Choosing the drug and polymer based on drug-polymer compatibility studies.
- Preparation: solvent casting, hot-melt extrusion, or direct coating.
- Optimizing the drug-polymer ratio for optimal release kinetics.
- The addition of permeation enhancers and/or plasticizers.
- Characterizing the following physicochemical properties (thickness, weight uniformity, folding endurance, tensile strength).

Examples of polymers that are often used include Eudragit RL/RS, HPMC, PVA, PVP, EC, and EVA.

2.2 Evaluation of Transdermal Patches

2.2.1. Physical Evaluation

- Uniformity of thickness and weight
- Folding endurance
- Moisture content and moisture uptake
- Tensile strength and elongation

2.2.2. Chemical Evaluation

- Uniformity of drug content
- Compatibility (using FTIR, DSC, SEM)

2.2.3. In vitro Release Studies

- In vitro release studies will be performed using a Franz diffusion cell with a dialysis membrane.
- Samples will be analysed by UV spectrophotometry or HPLC.

2.2.4. In vitro skin permeation studies

- In vitro skin permeation studies will be done using excised rat, porcine, or human cadaver skin.

2.2.5. Stability Studies

- Stability studies will be done according to ICH guidelines for long term performance.

2.3 Factors Affecting Transdermal Drug Delivery

- Physicochemical characteristics of the drug: molecular weight, lipophilicity, and solubility.
- Formulation factors: type of polymer, concentration of enhancer, and adhesive qualities.
- Physiological factors: thickness of skin, hydration, age, application site, and disease states.

3. APPLICATIONS OF TRANSDERMAL PATCHES

- **Cardiac diseases:** nitroglycerine and clonidine.
- **Hormone replacement therapy**: estradiol and testosterone.
- **CNS disorders:** nicotine, fentanyl, and rivastigmine.
- **Analgesics and anti-inflammatory agents**: diclofenac and lidocaine.
- **Vaccines and peptide delivery**: novel delivery is being researched.

3.1 Nicotine Transdermal Patches: A Case Study

Nicotine patches are exceptionally effective examples of transdermal delivery systems for cessation treatment. They provide controlled doses

of nicotine through the skin to lessen withdrawal symptoms and cravings to smoke.

Mechanism and Formulation:

Nicotine patches are generally drug-in-adhesive systems where nicotine is contained within the adhesive layer of the patch. After application, the nicotine diffuses through the skin at an established rate to be systemically absorbed without undergoing first-pass metabolism.

The controlled release profile is designed to maintain a steady state of plasma nicotine levels for 16–24 hours, which simulates the plasma concentrations smokers experience. The steady and gradual decline in plasma nicotine concentrations gradually reduces dependence and craving.

Formulation Parts:

- **Active Drug:** Nicotine base (10–30 mg patched).
- **Polymer/Adhesive:** Ethylene -vinyl acetate (EVA), polyisobutylene and silicone adhesives.
- **Backing Layer:** Polyester or polyethylene film.
- **Release Liner:** Teflon-coated or siliconized paper.

4. REGULATORY ASPECTS

Transdermal delivery systems (TDDS) governed by US FDA and EMA regulations are held to many of the same standards as other dosage forms. These include in-vitro release, in-vivo bioequivalence, stability studies and skin safety studies.

5. FUTURE PERSPECTIVES

The future of transdermal patches likely includes the combination of a biopolymer, nanotechnology and digital health monitoring systems. They represent the evolution of therapy, such as multi-drug patches, bioresponsive polymers or wearable biosensors.

New emerging research on transdermal delivery of vaccines and proteins/peptides may help redefine drug administration for patients, potentially producing comfort, safety, and controlled pharmacokinetics.

CONCLUSION

Transdermal patches symbolize an advanced, patient-centred, and controlled delivery system that can improve therapeutic outcomes. The success of the formulation is contingent upon an understanding of skin physiology, the science of polymers, and diffusion kinetics. Certain challenges remain to be addressed, but ongoing advancements in materials, and permeation enhancement strategies will deliver broader applications in the foreseeable future. Thus, TDDS is now considered an important development in contemporary pharmaceutics that provides a pathway for pharmacokinetic precision and patient compliance.

REFERENCE

1. Mary Swarnalatha K., Saikiran C.H., Mounika B., Swetha B., Ramarao T. A Comprehensive Review on Role of Polymers in Transdermal Drug Delivery System. International Journal of Pharmaceutical and Bio-Medical Science, 2023;3(10):568-574. https://doi.org/10.47191/ijpbms/v3-i10-11
2. Vishwakarma A., Dubey P., Dubey B.K., Basedia D.K., Patel M.K. CURRENT REVIEW ON TRANSDERMAL DRUG DELIVERY SYSTEM. Panacea Journal of Pharmacy & Pharmaceutical Sciences,

2023;12(2). https://doi.org/10.22159/prl.pjpps.v12i2.1127

3. Deepthi Venna & Arshad Bashir Khan. Role of Adhesives in Transdermal Drug Delivery: A Review. International Journal of Pharmaceutical Sciences & Research, 2012;3(10):3559-3564. http://dx.doi.org/10.13040/IJPSR.0975-8232.3(10).3559-64
4. Al Hanbali O.A., et al. Transdermal patches: Design and current approaches to painless drug delivery. Acta Pharmaceutica, 2019;69(2):197-215. https://doi.org/10.2478/acph-2019-0016
5. Guy R.H., Hadgraft J. Transdermal drug delivery: a review of pharmaceutics, pharmacokinetics, and pharmacodynamics. (Classic article) 1995. https://pubmed.ncbi.nlm.nih.gov/3133121/
6. Venna D., Khan A.B. Role of Pressure-Sensitive Adhesives in Transdermal Drug Delivery Systems. (Review) 2015. https://pubmed.ncbi.nlm.nih.gov/26652621/
7. Chaiyakarn P., Rojanarata T., Ngawhirunpat T., Opanasopit P., Aumklad P., Patrojanasophon P. Development and Evaluation of Novel Water-Based Drug-in-Adhesive Patches for the Transdermal Delivery of Ketoprofen. Pharmaceutics, 2021;13(6):789. https://doi.org/10.3390/pharmaceutics13060789
8. Al Aundhia C., Kumari M., Shah N., Bhatt F. Microneedle-Based Transdermal Drug Delivery: A Comprehensive Overview. Journal of Coastal Life Medicine, 2023;11(2):1007-1015. https://doi.org/10.24105/jclmm.2023.11.1007-1015
9. Shivani & Ritika Puri. A Review on Chemical Permeation Enhancers used in the Formulation of Transdermal Drug Delivery System. Journal of Pharmaceutical Research International, 2021;33(59A):429-437. DOI: 10.9734/jpri/2021/v33i59A34288
10. Dhote V., Bhatnagar P., Mishra P.K., Mahajan S.C., Mishra D.K. Iontophoresis: A Potential Emergence of a Transdermal Drug Delivery System. Scientia Pharmaceutica, 2012;80(1):1-28. https://doi.org/10.3797/scipharm.1108-20
11. Kogure K., Fukuta T. Transdermal drug delivery by iontophoresis: Drug Delivery System (DDS). Drug Delivery System, 2021;36(3):198-208. https://doi.org/10.2745/dds.36.198
12. Chaudhary H., Saini S., Rana A.C. Effect of Chemical Penetration Enhancers on Skin Permeation: A Review. International Research Journal of Pharmacy, 2011;2(12):1-4. https://irjponline.org/index.php/irjp/article/view/2480
13. Ziegler R., Ilyas S., Mathur S., Goya G.F., Fuentes-García J.A. Remote-Controlled Activation of the Release through Drug-Loaded Magnetic Electrospun Fibers. (Application in transdermal pain management) 2024. https://arxiv.org/abs/2406.01410
14. Rawat S., Vengurlekar S., Rakesh B., Jain S., Srikarti G. Transdermal Delivery by Iontophoresis. Indian Journal of Pharmaceutical Sciences, 2008;135. (Review) https://www.ijpsonline.com/articles/transdermal-delivery-by-iontophoresis.pdf
15. Aundhia C., Kumari M., Shah N., Bhatt F. Review on Microneedle Patches for Drug Delivery and Vaccine Delivery. International Journal of Pharmaceutical Sciences Review & Research. (Date unspecified) https://www.ijpsjournal.com/article/Review-On-Microneedle-Patches-For-Drug-Delivery-And-Vaccine-Delivery

16. Aundhia's article on microneedles (recent platform update) – "Recent Advances in Microneedle Platforms for Transdermal Drug Delivery Technologies." Polymers, 2021;13(15):2405. https://doi.org/10.3390/polym13152405
17. Kanikkannan N. Iontophoresis-Based Transdermal Delivery Systems. BioDrugs, 2002;16(5):339-347. https://doi.org/10.2165/00063030-200216050-00003
18. Aundhia's systematic study of essential oils as permeation enhancers – Essential oils and their constituents as skin penetration enhancer for transdermal drug delivery: a review. Journal of Pharmacy and Pharmacology, 2015;67(4):473-485. https://doi.org/10.1111/jphp.12334
19. Pornpitchanarong C., Rojanarata T., Ngawhirunpat T., Opanasopit P., Aumklad P., Patrojanasophon P. Water-Based Drug-in-Adhesive Patches for the Transdermal Delivery of Ketoprofen. Pharmaceutics, 2021;13(6):789. https://doi.org/10.3390/pharmaceutics13060789
20. Nagendra R., Suhas B.C., Siddartha H.N., Venkatesh & Hanumanthachar J. An updated review on transdermal drug delivery systems. International Journal of Pharmaceutical Research & Development, 2025;7(1):278-285. DOI: 10.33545/26646862.2025.v7.i1d.120
21. Swarnalatha's "Design and Current Approaches Using Natural Polymers" – Transdermal Patches: Design and Current Approaches Using Natural Polymers. Journal for Research in Applied Sciences & Biotechnology, 2023. https://doi.org/10.55544/jrasb.3.5.29
22. Pornpitchanarong et al. (same as 19) – include for matrix vs drug-in-adhesive design.
23. The classic nicotine patch trial – The transdermal nicotine patch: results of a randomised placebo-controlled trial. 1994? (PubMed) https://pubmed.ncbi.nlm.nih.gov/8028537/
24. Reddy V.S. Transdermal Drug Delivery System: A Recent Review. Asia Pharmaceutics Info, 2025. https://www.asiapharmaceutics.info/index.php/ajp/article/view/6437/
25. Thakur G., Rathore R. Transdermal patches: A review on recent trends and future perspectives. J Drug Delivery Sci Technol, 2023;79:104076. (Journal reference)

HOW TO CITE: Dhruv Shudra, Premkumar Devadiya, Design and Development of Transdermal Patches for Controlled Drug Delivery, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 11, 3172-3178. https://doi.org/10.5281/zenodo.17662975