International Journal of
Science, Architecture, Technology and Environment

# A Review on Transdermal Drug Delivery Systems

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*DOI: https://doi.org/10.63680/ijsate1125072.057*

## Abstract

Transdermal drug delivery systems (TDDS) represent an advanced and patient-friendly approach for the systemic administration of drugs through the skin. This route of delivery offers several advantages over conventional oral and parenteral methods, including avoidance of first-pass metabolism, sustained and controlled drug release, improved bioavailability, and enhanced patient compliance. Despite these benefits, the highly efficient barrier function of the skin, particularly the stratum corneum, poses a major challenge for effective drug permeation. Continuous research has led to the development of novel strategies such as chemical penetration enhancers, physical enhancement techniques, vesicular carriers, and microneedle-based systems to overcome these limitations. This review article discusses the fundamentals of transdermal drug delivery, skin anatomy relevant to permeation, components and design of transdermal patches, methods of preparation, evaluation parameters, clinical considerations, and recent advancements. The future prospects of TDDS in modern pharmaceutics are also highlighted.

***Keywords:*** Transdermal drug delivery system, skin permeability, transdermal patch, controlled drug release, penetration enhancers

## 1. Introduction

Transdermal drug delivery systems are dosage forms designed to deliver therapeutically effective amounts of drugs across the skin into systemic circulation. The concept of applying drugs to the skin for therapeutic purposes dates back several centuries; however, transdermal delivery as a controlled systemic approach gained prominence in the late twentieth century. The approval of the scopolamine transdermal patch for motion sickness in 1979 marked a significant milestone in this field.

TDDS provide a promising alternative to oral and injectable drug delivery systems. Oral administration often suffers from limitations such as variable absorption, gastrointestinal irritation, and extensive first-pass hepatic metabolism. Injectable routes, although effective, may cause pain, require trained personnel, and reduce patient adherence. In contrast, transdermal systems offer non-invasive, sustained, and controlled drug delivery with reduced dosing frequency.

Currently, several drugs such as nicotine, nitroglycerin, fentanyl, lidocaine, estradiol, testosterone, and clonidine are successfully administered via transdermal patches. Ongoing advances in formulation science and skin permeation technologies continue to expand the scope of drugs suitable for transdermal delivery.

## 2. Skin Anatomy and Physiology Relevant to Transdermal Drug Delivery

The skin is the largest organ of the human body and acts as a protective barrier against environmental hazards. From a drug delivery perspective, understanding skin structure is essential for designing effective TDDS.

### 2.1 Epidermis

The epidermis is the outermost layer of the skin and consists of multiple stratified layers. The most important layer influencing drug permeation is the stratum corneum, which is composed of dead, keratinized cells embedded in a lipid matrix. This layer is the primary rate-limiting barrier for transdermal drug transport.

The stratum corneum follows a “brick and mortar” model, where corneocytes act as protein-rich bricks and intercellular lipids function as mortar. Drug molecules can penetrate the stratum corneum through transcellular, intercellular, or appendageal pathways depending on their physicochemical properties.

### 2.2 Dermis

The dermis lies beneath the epidermis and consists of connective tissue containing blood vessels, lymphatic vessels, and nerve endings. Once a drug crosses the epidermis, it diffuses through the dermis and is absorbed into systemic circulation via capillaries. The dermis offers relatively less resistance to drug permeation compared to the stratum corneum.

### 2.3 Hypodermis

The hypodermis, or subcutaneous layer, is composed mainly of adipose tissue. It provides mechanical protection, thermal insulation, and support to the upper layers. Although it does not significantly limit drug diffusion, drugs must pass through this layer to reach systemic circulation.

## 3. Transdermal Drug Delivery Systems

A transdermal patch is an adhesive device applied to the skin that delivers a controlled dose of drug over a specified period. TDDS are designed to maintain consistent plasma drug levels and minimize fluctuations associated with conventional dosage forms.

### 3.1 Advantages of TDDS

- Avoidance of first-pass hepatic metabolism
- Controlled and sustained drug release
- Improved patient compliance
- Reduced gastrointestinal side effects
- Easy termination of therapy by patch removal

### 3.2 Limitations of TDDS

- Limited permeability of the skin
- Skin irritation or sensitization

- Suitability restricted to potent drugs with low molecular weight

## 4. Components of Transdermal Patches

A typical transdermal patch consists of several functional components:

### 4.1 Drug

The drug must possess suitable physicochemical properties such as low molecular weight, adequate lipophilicity, and high potency. Drugs with short biological half-lives or extensive first-pass metabolism are ideal candidates for TDDS.

### 4.2 Polymer Matrix

Polymers form the backbone of transdermal patches and control drug release. Commonly used polymers include natural polymers, synthetic elastomers, and synthetic polymers such as polyvinyl alcohol, polyethylene, and polymethyl methacrylate.

### 4.3 Pressure-Sensitive Adhesive

The adhesive layer ensures intimate contact between the patch and the skin. It should possess good adhesion properties without causing skin irritation or interfering with drug release.

### 4.4 Backing Layer

The backing layer protects the patch from external environmental factors and prevents drug loss. It should be impermeable, flexible, and chemically inert.

### 4.5 Release Liner

The release liner protects the adhesive surface during storage and is removed before application.

## 5. Design and Types of Transdermal Patches

Based on design, transdermal patches are classified as:

- Matrix systems: Drug is uniformly dispersed in a polymer matrix that controls release.
- Reservoir systems: Drug is stored in a reservoir and release is regulated by a rate-controlling membrane.

The selection of design depends on drug characteristics and desired release kinetics.

## 6. Methods of Preparation of Transdermal Patches

Various techniques are employed for the preparation of transdermal patches, including solvent casting, mercury substrate method, glass substrate method, circular Teflon mould method, and membrane-controlled systems. The choice of method depends on the type of polymer, drug solubility, and desired patch properties.

## 7. Evaluation of Transdermal Patches

Transdermal patches are evaluated using physicochemical, mechanical, and biological parameters.

### 7.1Physicochemical Evaluation

- Thickness and weight uniformity
- Drug content uniformity
- Moisture content and moisture loss

### 7.2Mechanical Properties

- Tensile strength
- Folding endurance
- Adhesive strength

### 7.3 In Vitro and In Vivo Studies

In vitro drug release and permeation studies are commonly performed using diffusion cells such as Franz diffusion cells. In vivo studies are conducted in animal models or human volunteers to assess pharmacokinetics, safety, and efficacy.

## 8. Clinical Considerations

Proper patient education is essential for the successful use of transdermal patches. Application site rotation, avoidance of damaged skin, and adherence to recommended usage duration help minimize adverse effects. Factors such as age, skin condition, body temperature, and site of application can influence drug absorption.

## 9. Recent Advances and Future Prospects

Recent innovations in TDDS include microneedle patches, iontophoresis, sonophoresis, electroporation, and nanocarrier-based systems. These technologies aim to enhance skin permeability and expand the range of drugs suitable for transdermal delivery. With continuous advancements in polymer science, nanotechnology, and biomedical engineering, TDDS are expected to play a crucial role in personalized and targeted drug therapy.

## 10. Conclusion

Transdermal drug delivery systems offer a safe, effective, and patient-friendly alternative to conventional drug delivery routes. By providing controlled drug release, improved bioavailability, and enhanced patient compliance, TDDS have become an important component of modern pharmaceutics.

Although challenges related to skin permeability and formulation stability remain, ongoing research and technological advancements are likely to overcome these limitations. The future of transdermal drug delivery systems appears promising, with significant potential to transform therapeutic practices.

## Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

## Funding

The author received no financial support for the research, authorship and publication of this article.

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