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Light Activated Drug Delivery System: A Novel Approach for Controlled and Targeted Therapy

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Abstract: *Light-Activated Drug Delivery Systems (LADDS) are advanced drug delivery systems that release drugs only when exposed to a specific wavelength of light. Unlike conventional drug delivery, which often causes uncontrolled drug release and systemic side effects, LADDS provide targeted and controlled drug release at the desired site and time. These systems use photoresponsive carriers such as liposomes, nanoparticles, hydrogels, and micelles, which respond to ultraviolet (UV), visible, or near-infrared (NIR) light. Light activation triggers mechanisms such as photo-cleavage, photo-isomerization, and photothermal effects, resulting in precise drug release. LADDS have promising applications in cancer therapy, dermatology, ophthalmology, gene delivery, and photodynamic therapy. Although challenges such as limited tissue penetration, high cost, and formulation complexity remain, ongoing advances in nanotechnology and photoresponsive materials are improving their clinical potential. Overall, light-activated drug delivery represents a promising strategy for safe, effective, and site-specific drug delivery.*

Keywords: Light activated drug delivery, stimuli-responsive systems, phototriggered release, nanoparticles, photodynamic therapy, controlled release.

I. INTRODUCTION

Conventional drug delivery systems release drugs in an uncontrolled manner, which may lead to reduced therapeutic efficacy and increased systemic toxicity. Modern pharmaceutics focuses on developing targeted and controlled drug delivery systems capable of releasing drugs at the desired site and time. Stimuli-responsive drug delivery systems respond to internal or external triggers such as temperature, pH, magnetic field, ultrasound, and light. Among these, light has gained considerable attention because of its non-invasive nature, high precision, and controllability.

Light activated drug delivery systems (LADDS) are designed to release drugs upon exposure to a specific wavelength of light. These systems provide better spatial and temporal control, thereby improving therapeutic efficacy and minimizing side effects.[1,3]

History

The therapeutic use of light dates back thousands of years when sunlight was used for treating skin diseases in ancient civilizations. Modern phototherapy was established by Niels Ryberg Finsen, who received the 1903 Nobel Prize for demonstrating the effectiveness of light therapy against lupus vulgaris. The concept evolved further with the development of photodynamic therapy and later photoresponsive nanocarriers capable of releasing drugs only after light exposure. Today, near-infrared (NIR)-responsive nanomedicine represents one of the most advanced forms of light-triggered drug delivery [5,6].

II. OBJECTIVES OF LIGHT ACTIVATED DDS

- Site-specific drug delivery
- Controlled and on-demand drug release
- Reduction of systemic toxicity

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- Improvement of therapeutic efficacy
- Enhancement of patient compliance
- Non-invasive drug activation [1,2]

III. PRINCIPLE OF LIGHT ACTIVATED DRUG DELIVERY

In LADDS, the drug is encapsulated within a photoresponsive carrier. Upon exposure to light of a specific wavelength, the photosensitive material undergoes structural or chemical changes leading to controlled drug release.[3,5]

The process includes:

1. Drug encapsulation in a light-sensitive carrier
2. Exposure to external light stimulus
3. Activation of photoresponsive molecules
4. Structural destabilization of carrier
5. Controlled release of drug at target site

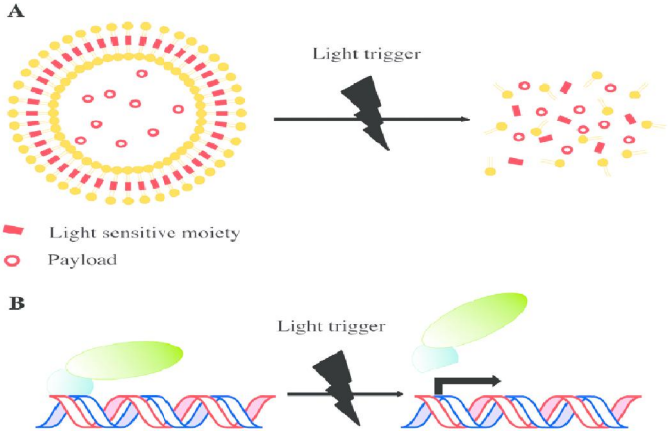

Fig no 1 :Light of delivery system

IV. TYPES OF LIGHT USED

4.1 Ultraviolet (UV) Light :

- Wavelength range: 200–400 nm
- UV light possesses high energy and can efficiently activate photoresponsive molecules.
- It is commonly used in early-stage light responsive drug delivery systems because it can induce rapid photo-cleavage and photo-isomerization reactions.
- UV light provides precise control over drug release but has limited penetration into biological tissues.
- Excessive exposure may cause phototoxicity, DNA damage, skin irritation, and tissue injury.
- Due to safety concerns, its clinical application is limited mainly to superficial tissues and dermatological treatments.[4,5]
- Applications:

1. Skin disorders
2. Surface tumor therapy
3. Controlled release studies in laboratories.[6,9]

4.2 Visible Light :

- Wavelength range: 400–700 nm
- Visible light is safer and less harmful compared to UV radiation.

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- It offers moderate tissue penetration and can activate various photosensitizers used in drug delivery systems.
- Different colors of visible light produce different therapeutic effects:
- Blue light (450–495 nm): Used in dermatological treatments and antimicrobial therapy.
- Green light (495–570 nm): Used in ophthalmic and vascular therapies.
- Red light (620–750 nm): Provides deeper penetration and is commonly used in photodynamic therapy.
- Visible light enables controlled and localized drug release with reduced toxicity.[4,6]

Applications:

1. Ophthalmic drug delivery
2. Acne and psoriasis treatment
3. Photodynamic cancer therapy.[6,9]

4.3 Near Infrared (NIR) Light :

- Wavelength range: 700–1000 nm
- NIR light has excellent tissue penetration ability compared to UV and visible light.
- It is considered the most promising light source for advanced drug delivery systems.
- NIR light causes minimal tissue damage and provides better safety and biocompatibility.
- It is widely used with nanoparticles such as gold nanoparticles, graphene oxide, and photothermal agents.
- NIR-responsive systems can trigger drug release through photothermal and photodynamic mechanisms.
- Because of its deeper penetration, NIR light is suitable for treating internal tumors and deep-seated tissues.[6,9]

Applications:

1. Cancer targeted therapy
2. Photothermal therapy
3. Smart nanocarrier-based drug delivery
4. Gene delivery systems[6,9]

4.4 Comparison of Different Types of Light

Type of Light	Wavelength	Tissue Penetration	Safety	Main Applications
UV Light	200–400 nm	Low	Low	Skin therapy, laboratory studies
Visible Light	400–700 nm	Moderate	Moderate to High	Ophthalmology, dermatology
NIR Light	700–1000 nm	High	High	Cancer therapy, nanomedicine

V. MECHANISM OF DRUG RELEASE

Light activated drug release mainly occurs through the following mechanisms:

5.1 Photo-cleavage

Light breaks chemical bonds in photoresponsive molecules, resulting in drug release.

5.2 Photo-isomerization

Light induces conformational changes in molecules such as azobenzene, altering carrier permeability.

5.3 Photothermal Effect

Photoabsorbing materials convert light into heat, causing disruption of carrier systems and release of drugs.

5.4 Photodynamic Action

Reactive oxygen species generated upon light exposure help in therapeutic action and drug release.[3,6]

VI. LIGHT RESPONSIVE DRUG CARRIERS

Different carrier systems are used in LADDS:

- Liposomes

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- Polymeric nanoparticles
- Hydrogels
- Micelles
- Dendrimers

VII. PHOTORESPONSIVE MATERIALS

Commonly used photoresponsive materials include:

- Azobenzene
- Coumarin
- Spiropyran
- Gold nanoparticles
- Graphene-based materials [4,8]

VIII. APPLICATIONS

8.1 Cancer Therapy

Provides tumor-specific drug release with reduced toxicity.

8.2 Dermatological Disorders

Useful in psoriasis, acne, and skin cancers.

8.3 Ophthalmic Drug Delivery

Allows localized treatment of ocular diseases.

8.4 Gene Delivery

Improves targeted nucleic acid delivery.

8.5 Photodynamic Therapy

Combines photosensitizers with light exposure for cancer treatment.[6,9]

IX. ADVANTAGES

1. Site-specific drug release
2. Reduced systemic side effects
3. Non-invasive triggering
4. Enhanced therapeutic efficacy
5. Improved patient compliance
6. Controlled and repeatable release [1,5]

X. LIMITATIONS

1. Limited penetration of UV and visible light
2. Risk of tissue damage
3. Requirement of specialized equipment
4. High formulation complexity
5. Stability issues during storage
6. High treatment cost
7. Limited clinical translation [1,9]

Critical Analysis :

1. Controlled drug release: LADDS can release the drug at a specific time after exposure to light, providing better control over treatment.

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2. Targeted action: Light can be directed toward a particular area, helping to reduce unnecessary drug exposure to healthy tissues.
3. Reduced side effects: Localized drug release may decrease systemic toxicity compared with conventional drug delivery.
4. Choice of light is important: UV, visible, and NIR light have different penetration abilities and safety profiles.
5. UV light has major limitations: It has poor tissue penetration and may cause phototoxicity, DNA damage, and tissue injury.
6. NIR light is more promising: NIR provides better tissue penetration and comparatively less tissue damage, making it more suitable for deeper tissues.
7. Complex formulation: Development of photoresponsive nanoparticles, liposomes, hydrogels, or other carriers can be technically difficult.
8. High treatment cost: Specialized materials and light-producing equipment can increase the overall cost.
9. Clinical translation is limited: Many advanced light-triggered delivery systems are still under research and are not widely used in routine clinical practice.
10. Promising applications: LADDS have potential in cancer therapy, dermatology, ophthalmology, gene delivery, and photodynamic therapy.

XI. RECENT ADVANCES

Recent developments in LADDS include:

- Use of NIR-responsive nanocarriers
- Dual stimuli-responsive systems
- Wearable light-triggered devices
- Microneedle-based photoactivated systems
- Combination with photothermal and photodynamic therapies [6-9,19]

XII. FUTURE PERSPECTIVES

Future research is focused on:

- Deeper tissue targeting systems
- More biocompatible photoresponsive materials
- Smart wearable therapeutic devices
- Personalized medicine approaches
- Integration with gene therapy and immunotherapy [1-2,19]

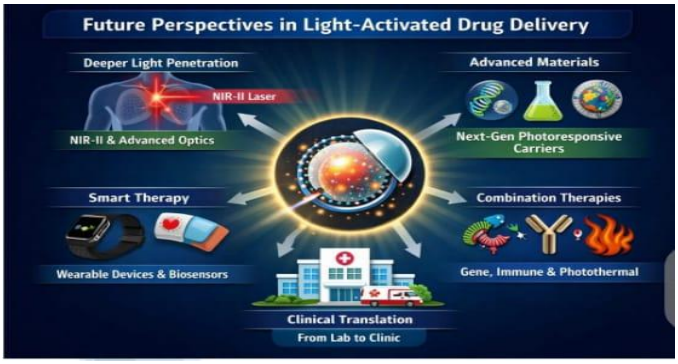

Fig.no2 : Future prospectives in Light –Activated drug delivery system

XIII. MARKETED PREPARATIONS

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Brand	Drug	Application	Light Used
Photofrin®	Porfimer sodium	Esophageal cancer	Red light
Visudyne®	Verteporfin	Macular degeneration	Visible light
Levulan® Kerastick	5-ALA	Actinic keratosis	Blue light
Metvix®	Methyl aminolevulinate	Skin cancer	Red light
Foscan®	Temoporfin	Head & neck cancer	Red light

XIV. CONCLUSION

Light activated drug delivery systems represent an advanced and promising strategy for controlled and targeted drug delivery. These systems provide excellent spatial and temporal control over drug release, improving therapeutic outcomes while minimizing adverse effects. Although several limitations remain, especially regarding tissue penetration and formulation complexity, continuous advancements in nanotechnology and photoresponsive materials are expected to enhance their clinical applicability in the future [1-9,19]

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