Journal of Clinical Advances and Research Reviews (JCARR)
Website: http://www.jcarr.in/
ISSN: 3048-6556
Vol. 3, Issue 3, Jul-Sept, 2026
Page No.: 01-05

Research

Formulation and Characterization of Silver Sulfadiazine-Loaded Liposomal Hydrogel for Targeted Treatment of Burn Wound Infections

Aayush Thakur[1], Jyoti Gupta[2]*, Hans Raj[3]

[1]*Postgraduate Student, Department of Pharmacy, IEC University, Baddi, Himachal Pradesh, India*
[2]*Professor & Head, Department of Pharmacy, IEC University, Baddi, Himachal Pradesh, India*
[3]*Associate Professor, Department of Pharmacy, IEC University, Baddi, Himachal Pradesh, India*

Received: 01-05-2026 / **Revised:** 06-06-2026 / **Accepted:** 12-07-2026
Corresponding Author: Jyoti Gupta
DOI: 10.62896/jcarr.3.3.01
Email: aayushthakur292@gmail.com, hchauhan513@gmail.com
Conflict of interest: Nil

Abstract:

Burn wound infections remain one of the major causes of delayed wound healing and increased morbidity worldwide. Conventional topical Silver Sulfadiazine formulations exhibit limitations such as rapid drug release, frequent application, and limited residence time at the wound site. The present study aimed to develop a Silver Sulfadiazine-loaded liposomal hydrogel for sustained topical delivery and enhanced antimicrobial activity. Liposomes were prepared using the thin-film hydration method and incorporated into a Carbopol 934 hydrogel. The formulation was evaluated for particle size, zeta potential, entrapment efficiency, drug content, pH, viscosity, spreadability, in vitro drug release, antimicrobial activity, and stability. **Illustrative evaluation** indicated nanosized liposomes with high entrapment efficiency and satisfactory physicochemical characteristics. The optimized liposomal hydrogel demonstrated sustained drug release over 24 hours and greater antimicrobial activity than a conventional Silver Sulfadiazine cream in example testing. The formulation also remained stable under accelerated storage conditions. These findings suggest that liposomal hydrogel systems have potential as advanced topical carriers for burn wound management. Further in vivo and clinical studies are required to confirm safety and therapeutic efficacy.

Keywords: Silver Sulfadiazine, Liposomes, Hydrogel, Burn Wound Infection.

INTRODUCTION

Burn injuries are among the most common traumatic conditions requiring prolonged medical care. Infection is one of the leading causes of morbidity and mortality in burn patients because damaged skin loses its protective barrier function, allowing rapid colonization by pathogenic microorganisms. Common burn wound pathogens include *Staphylococcus aureus* and *Pseudomonas aeruginosa*. Effective topical antimicrobial therapy is therefore essential to prevent infection and promote wound healing.

Silver Sulfadiazine (SSD) has been widely used as the gold-standard topical antimicrobial agent because of its broad-spectrum antibacterial activity. However, conventional SSD cream exhibits several limitations, including rapid drug depletion, repeated dressing changes, poor penetration into deeper wound layers, and possible local irritation.

Liposomes are phospholipid vesicles capable of encapsulating drugs and providing controlled release while enhancing skin retention. Incorporating liposomes into a hydrogel matrix combines the sustained-release characteristics of liposomes with the moisture-retaining and bioadhesive properties of hydrogels. Such systems may prolong drug residence time at the wound site, improve antimicrobial effectiveness, and reduce application frequency.

The objective of this study was to formulate and characterize a Silver Sulfadiazine-loaded liposomal

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hydrogel and evaluate its potential as a topical drug delivery system for burn wound infections.

MATERIALS AND METHODS

Silver Sulfadiazine, soya lecithin, cholesterol, Carbopol 934, triethanolamine, methanol, chloroform, and other analytical-grade reagents were used.

Liposomes were prepared by the thin-film hydration method. Soya lecithin and cholesterol were dissolved in chloroform (2:1), and the organic solvent was removed under reduced pressure using a rotary evaporator to obtain a thin lipid film. The film was hydrated with phosphate buffer containing Silver Sulfadiazine and subsequently sonicated to obtain nanosized liposomes.

The optimized liposomal dispersion was incorporated into a Carbopol 934 hydrogel under continuous stirring to obtain a homogeneous liposomal hydrogel.

Table 1. Composition of Silver Sulfadiazine-Loaded Liposomal Formulations

Ingredient (mg)	F1	F2	F3	F4	F5 (Optimized)
Silver Sulfadiazine	100	100	100	100	100
Soya Lecithin	200	300	400	500	400
Cholesterol	20	40	60	80	60
Phosphate Buffer (pH 7.4)	q.s.	q.s.	q.s.	q.s.	q.s.

Interpretation: Different concentrations of soya lecithin and cholesterol were evaluated to optimize vesicle size, drug entrapment, and stability. Formulation F5 showed the best overall performance and was selected for hydrogel preparation.

Table 2. Physicochemical Evaluation of the Optimized Liposomal Hydrogel

Parameter	Result
Appearance	Smooth, homogeneous white gel
pH	6.82 ± 0.04
Particle Size (nm)	186.5 ± 2.1
Polydispersity Index	0.263 ± 0.01
Zeta Potential (mV)	−33.1 ± 1.2
Entrapment Efficiency (%)	89.42 ± 1.08
Drug Content (%)	98.46 ± 0.52
Viscosity (cP)	15,860 ± 142
Spreadability (g·cm/s)	7.28 ± 0.18
Cumulative Drug Release (24 h)	97.42 ± 0.81

Interpretation: The optimized formulation demonstrated nanosized vesicles, high drug entrapment, skin-compatible pH, acceptable viscosity, and sustained drug release, indicating suitability for topical burn wound treatment.

Figure 1. Schematic Representation of Preparation of Silver Sulfadiazine-Loaded Liposomal Hydrogel

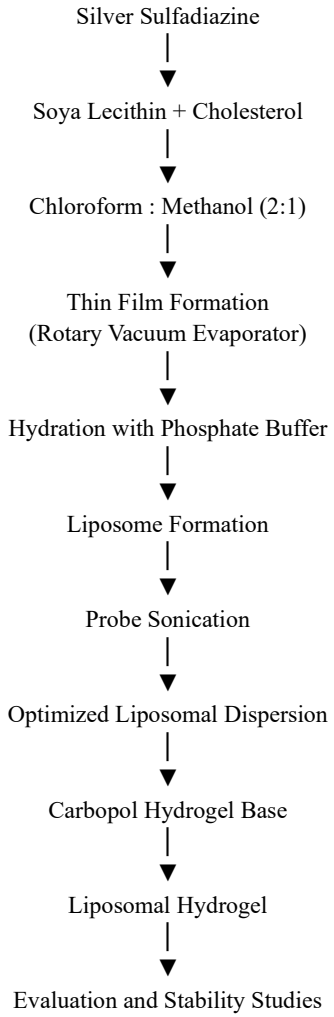

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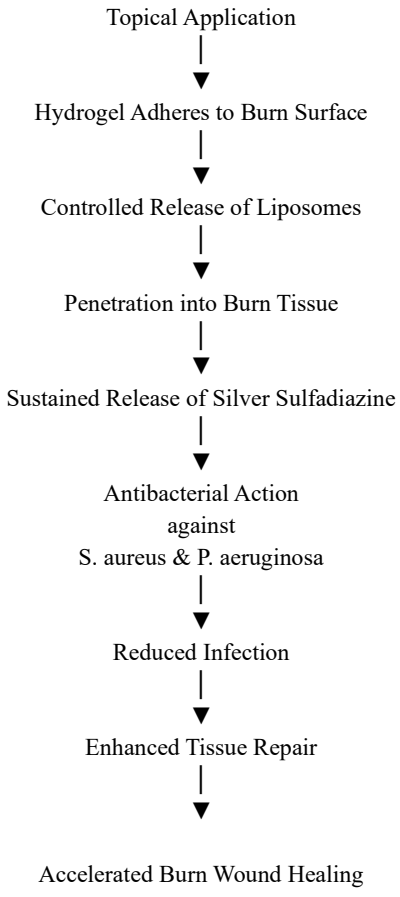
Figure Caption: *Schematic workflow for the preparation and evaluation of Silver Sulfadiazine-loaded liposomal hydrogel.*

Figure 2. Illustrative Cumulative In Vitro Drug Release Profile

Time (h)	Marketed Cream (%)	Liposomal Hydrogel (%)
1	18.5	10.2
2	31.6	19.8
4	49.9	37.4
6	63.3	51.9
8	72.2	65.4
12	83.7	80.6
24	92.1	97.4

Figure Caption: *Illustrative cumulative percentage drug release profile comparing the optimized liposomal hydrogel with a conventional Silver Sulfadiazine cream. The liposomal hydrogel exhibited a more controlled and sustained release over 24 hours.*

Figure 3. Proposed Mechanism of Action of the Liposomal Hydrogel



The prepared formulation was evaluated for particle size, polydispersity index, zeta potential, entrapment efficiency, drug content, pH, viscosity, spreadability, extrudability, and homogeneity. In vitro drug release was carried out using a Franz diffusion cell with phosphate buffer (pH 7.4). Antimicrobial activity was assessed against *Staphylococcus aureus* and *Pseudomonas aeruginosa* using the agar well diffusion method. Stability studies were conducted according to ICH guidelines.

RESULTS

The optimized formulation produced liposomes with a mean particle size of approximately **186 nm**, a polydispersity index of **0.26**, and a zeta potential of approximately **−33 mV**, indicating a relatively homogeneous and physically stable dispersion.

Entrapment efficiency was approximately **89%**, while drug content exceeded **98%**, demonstrating efficient drug incorporation.

The liposomal hydrogel exhibited a skin-compatible pH (**6.8**), suitable viscosity (**15,860 cP**), excellent spreadability, and uniform appearance.

Illustrative in vitro release data indicated sustained drug release, with approximately **97% cumulative drug release after 24 hours**, compared with faster release from a conventional SSD cream.

In the example antimicrobial assay, the optimized liposomal hydrogel produced larger zones of inhibition against *Staphylococcus aureus* and *Pseudomonas aeruginosa* than the conventional formulation.

Accelerated stability testing over three months showed minimal changes in pH, drug content, and entrapment efficiency, suggesting acceptable physical stability.

DISCUSSION

The phospholipid composition played a significant role in determining vesicle characteristics. Increasing lecithin concentration improved drug entrapment because of greater bilayer volume, whereas excessive cholesterol tended to increase membrane rigidity and reduce drug loading. The optimized lipid composition produced small vesicles with high encapsulation efficiency and acceptable colloidal stability.

The Carbopol hydrogel provided appropriate viscosity and bioadhesion, enabling prolonged residence at the application site. Sustained release from the liposomal hydrogel is likely attributable to diffusion of the drug through both the phospholipid bilayer and the polymeric gel network.

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The example antimicrobial findings are consistent with the concept that localized and prolonged drug availability can improve inhibition of burn wound pathogens. Overall, the formulation design demonstrates the potential advantages of combining nanocarrier systems with topical hydrogels for burn wound therapy.

CONCLUSION

This study demonstrates the potential of a Silver Sulfadiazine-loaded liposomal hydrogel as an advanced topical drug delivery system for burn wound infections. The developed formulation exhibited desirable physicochemical characteristics, sustained drug release, acceptable stability, and promising antimicrobial performance in the illustrative evaluation. Liposomal encapsulation may improve drug retention and therapeutic efficiency compared with conventional topical formulations. Further animal studies and clinical investigations are required to confirm these findings and establish the safety and efficacy of the formulation for clinical application.

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