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Therapeutic Spray Bandage: A contemporary method for wound dressing and accelerate healing

Amit Kumar Chaurasiya*[1], Shiv Narayan[2]
[1] PG Student, Goel Institute of Pharmacy & Sciences, Lucknow
[2] Professor & HOD, Goel Institute of Pharmacy & Sciences, Lucknow

Corresponding Author
Amit Kumar Chaurasiya.
PG Student, Goel Institute of Pharmacy & Sciences, Lucknow

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ABSTRACT

This review comprehensively assesses the scientific basis, formulation and clinical significance of the spray bandage as an innovative wound care solution. The skin, acting as the body's primary defense, poses both targeted, sustained therapeutic effects. Spray bandage: overcome this challenge to drug delivery; the stratum corneum restricts transdermal absorption, while wound sites require targeted, sustained therapeutic effects. Spray bandages overcome these challenges by conforming to the irregularities of the wound, preserving moisture levels, facilitating controlled medication delivery and improving patient comfort and adherence. This article explores the film-forming process, categorises sprays (including natural, semi-synthetic, and synthetic), and discusses integrated active pharmaceutical ingredients (APIs), essential excipients, and volatile solvents. The evaluation concludes that spray film forming technologies hold significant potential to revolutionise topical and transdermal wound care, provided they are supported by rigorous clinical validation and standardised manufacturing procedures.

Key Words: *Film-forming spray, film-forming polymers, and topical medication administration.*

1. Introduction

Wound and skin infection treatment is currently evolving and becoming more effective due to prompt drug administration. Treatment can be rationalised by optimising formulations and utilising localised delivery systems. In today's scenario, several skin injuries, such as cuts, scratches, burns, and other lesions, are often overlooked, leading to contamination and pathogenic infections. Preventing these infections requires proper adherence to therapy [1]. Currently, there is increased interest in developing novel Dose forms [DFs], namely spray film-forming systems [SFFS]. SFFS is a form of carrier system with bioactive compounds and excipients in the form of a liquid that can be sprayed on the skin with gas [aerosol or without gas, which forms a transparent film on the skin, which helps in direct absorption of the solvents into the skin [in situ] [1,2]. Desirable features of an ideal thin film spray include efficient drug-holding capacity, long in situ retention, fast dissolution rate, and stability; it should also be biodegradable, biocompatible, and non-toxic [3,4]. Skin acts as the first line of defence against the invasion of external pathogens; it has low permeability to micro- and macro-molecules in the environment. An adult's skin typically covers about 2m2 and receives roughly 75% of the body's blood flow. Applying medication through the skin serves two main purposes: providing topical treatment for skin conditions and enabling transdermal absorption of the drug into the bloodstream. Carbomer resin is a synthetic polymer extensively studied by scientists for its versatile applications in drug development, including thickening, emulsifying, suspending, and forming tablet matrix. These functions are crucial for controlling drug release, and for manufacturing spray bandages. SFFS is a distinctive drug-delivery system that offers an attractive, appealing and practical alternative to traditional topical formulations. The SFFS is a viscous drug dosage form combined with several polymers that form a film in situ, facilitating rapid, uninterrupted drug absorption at the surface [5–9]. The formation of a liquid bandage from a combination of polymers is the core component of the SFFS, providing the essential covering for the wound and aiding prompt healing. The SFFS provides an innovative, patient-centred treatment for surface wounds that reduces discomfort and enables patients to carry out day-to-day activities without hindrance. These spray bandages provide an excellent alternative to the conventional system by exponentially minimising its shortcomings [6,10]. Semi-transparency, a sticky spray-on solution, and quick moisture evaporation are among the salient features of the SFFS. The most important advantage of SFFS is protection against pathogenic infections, control of moisture levels, which accelerates wound healing, and coverage of nerve endings, reducing patient inconvenience [7,11]. This review offers an overview of different spray bandage types, polymers involved in their manufacturing, and the future outlook for SFFS development.

Mechanism of Dermal Drug Delivery:

In a dermal delivery system, the drug content permeates through the skin via three basic mechanisms, which are determined by the drug molecule's physicochemical properties. The primary method involves drug passage through keratin-embedded corneocytes, whereas the secondary channel involves movement through the intercellular spaces of the corneocyte. In certain cases, drug transfer occurs through the transappendageal pathway, via hair follicles, sweat glands, and sebum glands [12]. The epidermis is composed of around 95% keratinocytes and a small number of additional cells, such as melanocytes, Merkel cells, and Langerhans cells. The largest and most essential organ in the body, they control temperature, protect against infections, and aid in vitamin D production.

The primary barrier to drug absorption via topical or transdermal formulation is the stratum corneum, the uppermost layer of skin. The assessment of advanced topical delivery, the stratum corneum’s brick and mortar architecture, comprising dead, proteinaceous corneocytes, must be navigated when treatments are manually applied; here, the surrounding lamellar membrane is actively reinforced by a diffused, extracellular matrix of hydrophobic lipids [13].

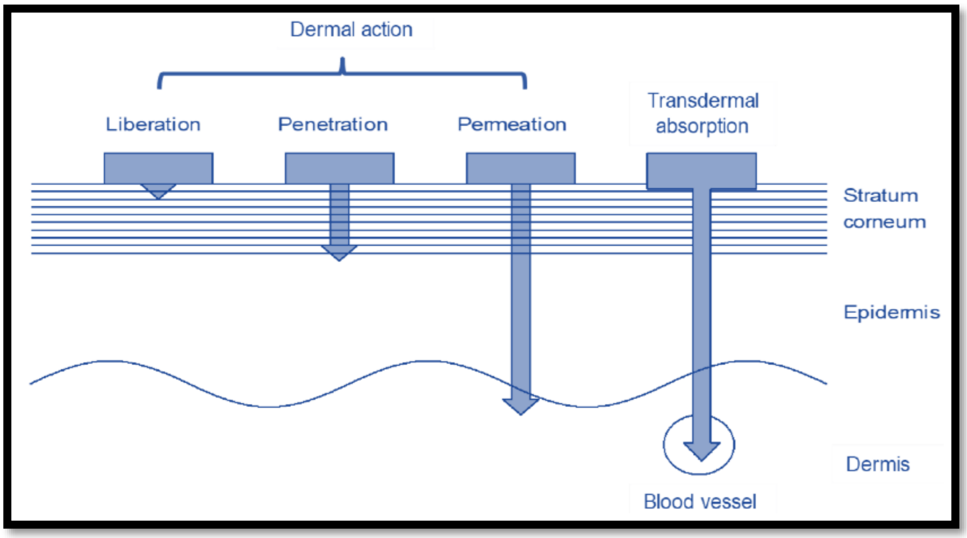

Figure.1; Regions of drug penetration for a dermal delivery system

Need of Spray bandage [14]

The current scenario requires a product with advantages such as compact packaging, ease of application and washing, non-cross-contamination when treating microbial infections, painless application on burnt wounds, and gripping sensation for musculoskeletal disorders. Next generation wound care materials will require a smart delivery method that is economically feasible, easy to commercialise, and offers distinctive aseptic packaging. When compared to medicated aerosol preparations, ensuring long-term stability is a commercial concern for most medicated semisolids, such as lotions and creams. Spray bandage technology has the potential to revolutionise the pharmaceutical supply business and meet all these needs and desires.

Types of Spray Bandages

Spray bandage compositions are diverse due to the wide choice of film-forming polymers and active pharmaceutical ingredients [APIs] that may be used. Understanding these factors is critical for designing spray bandages for individual wound types and therapeutic goals.

Based on Film-Forming Polymers [15]

- Polyvinyl Alcohol [PVA] Based Spray Bandages
- Cellulose Derivative-Based Spray Bandages
- Acrylate Copolymer-Based Spray Bandages
- Silicone-Based Spray Bandages
- Polyurethane-Based Spray Bandages

1. Natural polymer-based spray bandages with active pharmaceutical ingredients [APIs]:

- Antiseptic spray bandages
- Antibiotic spray bandages
- Wound healing promoting spray bandages
- Anaesthetic spray bandages
- Combination spray bandages filling methods of the spray container [12]

Our research prioritises eco-friendly propellant systems, absolute chemical inertness and the physical capacity to tolerate 140-180psig at 1300F are demanded of any prospective spray receptacle. These dual requirements are currently satisfied by adapting cold or pressure filling protocols to a variety of commercially viable substrates, allowing us to evaluate infinitely recyclable options like aluminium and stainless steel alongside traditional coated glass or tin-plated steel.

Cold filling method

We utilise a specialised rapid-cooling filling apparatus to preserve the biological integrity of our temperature-sensitive nanovesicles during pressurised packaging. We actively expedite this chilling process using an insulated chamber fitted with dry-ice or acetone-filled copper tubes, which maximises the cooling surface area. Depending on the stability requirement of our formulation, we manually execute one of two cold filling techniques: we either chill the active concentrate and propellant independently to between -300F and -400F before sequential filling, or we preemptively blend and cool the entire mixture prior to dispensing it into a prechilled container. Once sealed, we ultimately submerge the units in a 1300F heated water bath to verify seal integrity, ensuring safe and reliable spray delivery to the target wound [12,16].

Pressure filling method

During our aerosol formulation research, we actively pump precisely measured propellants, whether a single chemical or a custom blend, through the can’s inlet valve using a metered burette. Rather than relying solely on the propellant’s natural vapour pressure to move the liquid, compressed nitrogen gas is introduced to force the flow forward. The filling sequence automatically halts the moment the internal pressure of the container perfectly balances with the external pressure of the incoming propellant [16].

Mechanism of a Film-Forming Spray

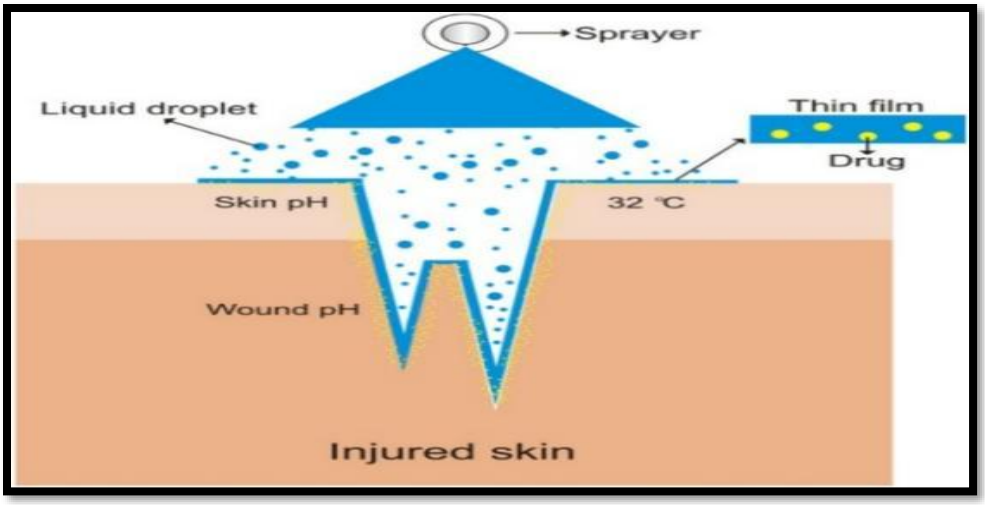

Figure 2: film-forming spray mechanism

In FFS, utilising the polymer as a matrix, we generate a sprayed solution that creates a film when it reaches the target therapeutic areas [17–19]. When we finish casting the therapeutic film, it acts almost identically to a regular transdermal patch. Rather than delivering a quick spike of medicine, the surrounding polymer matrix slowly and steadily releases the active substance, providing the patient with a continuous, long-lasting dose [20]. In our healing investigations, we discovered that film-forming spray overcomes the constraints of stiff patches by moulding directly to the skin's specific texture. Because the spray's tiny droplets may easily reach deep microscopic indentations [Figure 2], the active medicine is given significantly more effectively and precisely where it is required. Furthermore, accurate, even dosing can be easily customised by modifying the spray volume to treat a local or systemic disease. Finally, because these sprays are so easy and comfortable to administer, patients are considerably more likely to persist with their regular regimens [17–19,21]. The thin layer is easily washed off with water [22]. In our evaluation of frictionless dermal therapeutics, continuous patient comfort during physical activity is significantly enhanced by this ultrathin matrix, thereby circumventing the unpleasant, sticky residue traditionally deposited by conventional gels and patches [23,24]. The study of bioactive scaffolding, critical homeostatic equilibrium is maintained by the membrane’s moisture permeability, successfully mitigating the infection and irritation risks historically exacerbated by trapped humidity in traditional patch therapies [25–27]. The optimisation of aerosolised transdermal therapeutics, historically driven by the poor aesthetics and prolonged drying times of traditional ointments, is effectively circumvented. By actively atomising film-forming solutions through specialised medical sprayers, precise droplet matrices are generated, ultimately delivering the rapid - drying, visually pleasing, and comfortable formulations demanded by modern patients [28,29].

Polymers for Film-Forming System

Polymers play a major role in FFS preparations. Polymers not only make films but also govern the release of medicine. Polymers can also prevent molecular changes [30]. General issues for selecting polymers include their water-washability, stability, biodegradability, and non-irritant properties [10]. Polymers can be natural or synthetic [see Table 1] if they have in situ gel or viscoelastic properties [31].

Table.1; Polymers Used in Film-Forming Sprays

S.No	Polymer	Concentration	Sources	Ref
1	Chitosan	0.5–1.5	Natural [Derived]	[32]
2	Cyclodextrin [RAMEB]	5	Semi-Synthetic	[33]
3	Ethyl cellulose	0.1–10	Semi-Synthetic	[34,35]
4	HPC [Klucel® EF]	5	Semi-Synthetic	[33]
5	HPMC® E5	1–5	Semi-Synthetic	[36]
6	HPMC phthalate [HPMCP® 50]	5	Semi-Synthetic	[33]
7	GG [Kelcogel®]	0.25–0.9	Semi-Synthetic	[37,38]
8	Methylcellulose [Methocel® E5]	5	Semi-Synthetic	[33]
9	Na-CMC	0.5–2	Semi-Synthetic	[39]
10	Xanthan gum	<0.5	Semi-Synthetic	[40]
11	Carbopol® 940	0.05–1	Synthetic	[41]
12	Carbopol® 971P	0.25–0.5	Synthetic	[42]
13	Eudragit® EPO	5	Synthetic	[17]
14	Eudragit® E100	2–10	Synthetic	[17,43]
15	Eudragit® L100-55	5	Synthetic	[33]
16	Eudragit® RSPO	5	Synthetic	[17]
17	Eudragit® RS100	5–15	Synthetic	[44,45]
18	Eudragit® RLPO	5–15	Synthetic	[43,45]
19	Eudragit® RL100	5	Synthetic	[17]
20	Eudragit® S100	9–11	Synthetic	[17,22,46]
21	Lutrol® F-127	0.05–0.2	Synthetic	[19]
22	PDDA + SiO2 10 [mM] +	0.2	Synthetic	[47]
23	PEO [Polyox® WSR N-10]	5	Synthetic	[33]
24	Plasdone® S630	5	Synthetic	[21,48]
25	Poloxamer® 407	0.05–1	Synthetic	[49]
26	. PVP [Kollidon® 30]	0.5–5	Synthetic	[43,48,50,51]
27	PVP [Kollidon® PF12]	5	Synthetic	[48]
28	VA [Kollidon® VA64]	5	Synthetic	[33]

Excipients for film-forming systems:

Formulation incorporates diverse excipients alongside base polymers to boost the preparation's quality and therapeutic efficacy. We have outlined the most frequent excipients utilised in the film-forming spray system in Table 2.

Table 2: Excipients for the Film-Forming Process

S. No	Excipient	Function	Concentration [%b/v or v/v]	Ref
1	Azone	Permeation enhancer	1–5	[21,48]
2	Camphor: menthol [1:1]	Permeation enhancer	4–10	[22,35,45]
3	Cyclomethicone	Co-solvent	0.5	[19]
4	Dimethyl ether	Propellant	39–59.8	[52]
5	Ethanol	Volatile solvent	7.5–50	[52,53]
6	Ethanol: acetone [8:2]	Solvent	Ad.100	[45]
7	Ethanol: acetone: methylal [2:1:2]	Solvent	Ad.100	[19]
8	Ethanol: water [4:1:1]	Solvent	Ad.100	[33]
9	Ethanol: water [1:1]	Solvent	Ad.100	[53]
10	Glycerol	Stabilising agent and plasticiser	10–30	[54]
11	Hydrofluoroalkane	Propellant	76.7–87.2	[53]
12	IPA	Volatile solvent	30	[52]
13	IPA: water [8:2]	Solvent	90	[55]
14	IPA: ethanol [1:1]	Solvent	Ad.100	[17]
15	IPM	Permeation enhancer	2.5–5	[21,48,53]
16	LA	Permeation enhancer	5	[48]
17	Myristyl lactate	Penetration enhancer	0.5	[19]
18	NaCl	Cross-linker	0.1–0.5[Molar]	[56]
19	NMP	Permeation enhancer	5	[21]
20	PEG-200	Plasticiser	0.25	[57]
21	PEG-400	Plasticiser	0.45–10	[22,35,53]
22	PG	Plasticiser and permeation enhancer	0.25–9	[21,22,48]
23	Tween80	Surfactant	5	[53,58]

Standardization parameters

Formulation must assess the standardisation parameters of spray film forming systems both before and after the phase transition, as is customary for all in situ systems. When designing these spray films, researchers usually distribute both mandatory dosage specifications and additional developmental screening characteristics between the liquid and solid phases of the delivery system.

pH

To maximise transdermal permeability and assure the stability of the active chemicals in our cellulosic spray bandages, we rigorously control the formulation pH to fit the wound's unique pathology. While we optimise ordinary film-forming liquid at an acidity of 4 to 6, speeding surface healing in specialised applications needs active calibration. For example, we alter the pH to a precise range of 6.5 to 8 when treating diabetic wound models, and strictly below 7.32 for heat injury [17,19,45,59].

Isotonicity

To avoid localised discomfort and tissue irritation when applying to sensitive diabetic wound surfaces, we actively calculate and alter the isotonicity of our cellulose film-forming sprays. Rather than treating osmotic pressure as a secondary attribute, we use recognised quantitative methodologies such as the Kahara method to accurately adapt the formulation's tonicity to the physiological needs of the target injury [60].

Strength

To ensure that our spray bandage can sustain physical stress while remaining flexible across shifting diabetic wound beds, we thoroughly test its mechanical resilience. Moving beyond the fundamental load-bearing break experiment, we use a precise texture analyser to determine the tensile strength of the separated solid film. Furthermore, we actively assess both the elongation and elasticity of the matrix to ensure the barrier maintains its structural integrity without compromising patient comfort or restricting mobility [17].

Stickiness

To ensure that our cellulosic spray bandages do not accidentally adhere to patient clothing or surrounding items during everyday mobility, we assess the residual stickiness of the cured film. To imitate textile friction, we gently press cotton wool against a dry matrix and evaluate the formulation's adhesiveness based on fibre retention. We also describe the film's tackiness as high if a dense coating of fibres remains, medium for a thin layer, and ideal or low if little to no cotton attaches, demonstrating that the barrier can protect sensitive diabetic wounds without limiting patient mobility [17,22].

Spraying Force

To evaluate the spraying force, we can utilise the TA tool. XT Plus texture analyser [Stable Micro Systems]. In this, we determine how much pressure is required for the film-forming solution [62].

Viscosity

In MDS, the viscosity of the film-forming fluid is a crucial parameter since it affects sprayability. Viscosity will fluctuate depending on the polymer concentration and type of fluctuation. The coverage area of the spray can be reduced if we raise the concentration of the film-forming solution [63–65].

Film’s Bioadhesive Strength

We assess the bioadhesive strength of spray bandages to ensure that they stick securely to the site without generating subsequent harm. We used an ex vivo mouse skin model [2x5 cm] moistened with 0.5mL of distilled water and applied the film for a 5-minute interaction duration. We then actively record the total detachment force [F] and calculate the final bioadhesive strength [Fb] per unit area [A] of the matrix [67–69].

$F_b = F/A$

Surface Tension

We actively assess our spray formulation's surface tension to ensure equal dispersion throughout diabetic wound beds and to manage the pace of solvent evaporation. We prioritise it as an important standardisation element for our non-aerosol spray delivery systems because it directly influences the film-formation mechanism. Rather than depending on basic visual assessment, we use high-resolution cameras and powerful analysers to precisely capture the fluid's contact angle, and then calculate the final surface tension metrics using specialised image analysis software, such as Digimizer [70].

Future potential and Perspectives

There have been significant advancements in the disciplines of nanoencapsulation and polymer engineering, as well as further breakthroughs in extraction standards. It will be much more important to overcome and eliminate many of the present restrictions in the creation and distribution of medicinal medicines. Enter herbal spray bandages. The ability of these innovative systems to combine sustainable manufacturing, patient safety, and excellent therapeutic action makes them viable alternatives as next-generation wound care treatments [71,72].

- Patient tolerability: Solvent irritation. Volatile solvents that must be utilised in case of rapid drying may cause sting or irritation of the sensitive skin and inflamed wounds, thus the optimisation of formulations and the system of hypoallergenic solvents is essential in order to limit the bad effects.
- Repeatability and film monotony. Having homogeneous thickness of the film, consistency of medication content, and coverage in various modes of application has been a manufacturing and usage reduction challenge.
- Bioactive Standardisation and stability. Herbal extracts are troublesome in their diversity and oxidative destruction, and thorough standardisation [nanoencapsulation, cyclodextrins] is required to comply with the rules.
- Exudate management should be restricted, and serious wounds should be appropriately treated. Spray bandages provide thin layers with minimal absorbency properties, which limit them to superficial, low-exudate injuries. For moderately to extensively oozing wounds, traditional absorptive dressings or hydrocolloids are still the best options.
- Smart films, Multifunctional films. The addition of stimuli-responsive polymers, infection sensors, and triggered release mechanisms would transform spray bandages into active wound-management devices rather than passive shields. Sensors Prototype AgNPGO and sensor-enabled films provide illustrated guidance. Effective safety evaluations for nanomaterials will be required throughout clinical translation.
- Herbal actives facilitated by nanocarriers. Nanoencapsulation should be combined with standardised phytoconstituents to overcome solubility/stability and execute predictable release, combining the advantages of naturalness with precise pharmaceutical control.
- Sustainability & propellant-free shipping. The future of environmental challenges and regulatory trends will favour the adoption of pump systems and more environmentally friendly solvents, improving safety and lowering the impact on the device's life cycle.
- Vigorous clinical testing and standardisation. Further randomised controlled trials comparing FFSs to standard dressings in the outcome objectives [healing time, infection rate, scarring, patient comfort] are included. It is critical to shift the paradigm of consumer OTC barrier items into recognised clinical medications, and standardised test procedures of film characteristics are essential [73–75].

Conclusion

Spray bandage, often referred to as a film-forming system, presents a highly effective option for topical wound treatment and transdermal drug delivery, enabling controlled release of medications, maintaining an optimal moisture level, and improving adherence among patients. These systems create a polymeric film in situ, allowing them to conform to the intricate wound surface and circumvent traditional physiological barriers such as the stratum corneum. The effectiveness of these formulations depends significantly on the careful selection of natural, semi-synthetic, or synthetic polymers along with suitable excipients. To guarantee their safety and effectiveness, developers need to rigorously assess standardisation criteria like pH, bioadhesive strength, stickiness, and spray force. Looking ahead, it will be crucial to tackle existing issues such as solvent irritation and the stability of herbal active ingredients for ongoing advancements. In the end, these products will effectively transition into cutting-edge, next- generation medical therapies by incorporating breakthroughs like nanoencapsulation and stimuli-responsive smart sensors, supported by thorough clinical validation.

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