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SMART FILMS ON SKIN: THE EVOLVING LANDSCAPE OF FILM-FORMING DRUG-DELIVERY SYSTEMS

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ABSTRACT

Film-forming systems (FFS) are emerging as innovative topical and transdermal drug-delivery platforms designed to overcome the limitations of traditional dosage forms such as creams, gels, and patches. These systems consist of drugs incorporated into polymeric solutions, gels, or emulsions that transform into thin, flexible films upon solvent evaporation after skin application. By forming an adherent film, FFS provide prolonged contact with the skin, controlled and sustained drug release, improved bioavailability, and enhanced patient compliance. Unlike patches, they offer better cosmetic acceptability, reduced irritation, and superior conformity to skin contours. Key components include polymers, plasticizers, volatile solvents, and suitable drugs with optimal physicochemical properties for skin permeation. FFS have demonstrated applications across wound healing, antifungal therapy, pain management, anti-inflammatory delivery, and protective barrier formation. Evaluation parameters such as pH, viscosity, tensile strength, drying time, drug content, permeation, spray characteristics, and stability ensure performance and safety. Although promising, few marketed products exist due to limited clinical data. Continued research is needed to optimize formulation efficiency and establish FFS as reliable alternatives for topical and transdermal drug delivery**.** This review provides an in-depth exploration of film-forming systems, highlighting their principles, mechanisms, essential formulation components, types, evaluation methods, marketed preparations, therapeutic applications, and future prospects in topical drug delivery.

KEYWORDS: Film-forming systems, Topical drug delivery, Transdermal delivery, Polymeric films, Sustained release, Skin permeation.

1. INTRODUCTION

The main challenge facing pharmaceutical research is creating new technologies to give formulations unique qualities that overcome the therapeutic limitations of conventional dosage forms. These qualities include the ability to carry multiple active ingredients, adjustable release profiles, flexibility of use, and improved patient availability and compliance.[5] The skin is an increasingly investigated route of administration, whether it is for topical application of dermatological dysfunctions or transdermal application of systemic action, because it has no gastrointestinal side effects, avoids the metabolization of active ingredients by first pass effect, and is easy to apply in people who have difficulty swallowing, such as children and the elderly. Though it is a promising route of administration, it is not so easily passable because the skin's primary role is to act as a barrier against external substances.[5]

Due to its many advantages over oral drug administration, topical drug delivery is one of the most often used methods for systemic, cutaneous, and superficial drug delivery. Topical drug distribution is preferable because it avoids certain drawbacks of the oral route, such as enzyme interference, low pH impact, and first-pass metabolism. Topical medications are administered using lotion, creams, ointments, sprays, solutions, gels, and bioadhesive pre-formulated films called patches in order to enhance therapeutic efficacy or pharmacokinetic characteristics. The previously

mentioned formulations have several disadvantages, such as stickiness, frequent dosage, and reduced drug absorption. Nevertheless, even if the patch is a better formulation with fewer problems, it still has drawbacks. Additionally, patch preparations are frequently linked to blistering, irritation, and hypersensitivity.[1]

A) The skin - The biggest organ in the body, the skin accounts for over 15% of an adult's total body weight. In addition to preventing excessive water loss from the body and playing a part in thermoregulation, it carries out other vital functions, including defense against external physical, chemical, and biological attackers. The integumentary system is composed of the skin and structures generated from it.[2] Fig.1

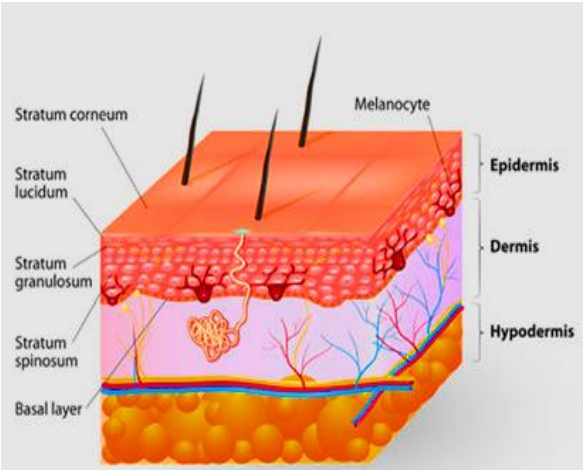

Fig. 1: Anatomy of Skin Layer.

B. Skin Anatomy

The three layers that comprise the skin are the dermis, subcutaneous tissue, and epidermis. The protective protein keratin, a long, thread-like strand, is produced by a specific type of cells called keratinocytes, which make up the epidermis, the outermost layer. The primary component of the dermis, the intermediate layer, is collagen, a fibrillary structural protein. The panniculus, or subcutaneous tissue, which is composed of microscopic fat cell lobes called lipocytes, is where the dermis is found. The thicknesses of these layers vary greatly depending on their location within the body's anatomy. A variety of appendages, including hair follicles and ecocrine and apocrine sweat glands, are also connected to the skin. The skin surface is sensitive to temperature fluctuations, and a thick layer of fatty tissue beneath the skin's surface. Many of the skin's cells are also temperature, pressure, touch, pain, and itching sensitive. Skin composed of 3 main layers:

• Epidermis • Dermis • Hypodermis

a) Epidermis

Depending on the size and quantity of epidermal cells, the multilayered epidermal layer on the palms and feet varies in thickness by 0.8 mm. Point in the direction of the eyelid by 0.06 mm. The skin's outermost layer is referred to as the stratum corneum. It contains ten to twenty-five layers of dead keratinocytes, or keratinocytes. It is impermeable and flexible. The main obstacle to drug penetration is the stratum corneum.[2]

b) Dermis

Blood vessels and lymphatic vessels are found in the dermis, which is 3–5 mm thick. Maintaining body temperature depends on blood flow to the skin. Additionally, it removes waste and impurities from the skin while nourishing and oxygenating it. Most molecules can get through the skin barrier through capillaries, which are about 0.2 mm away from the skin. Consequently, the concentration gradient required for transdermal penetration is supplied by the concentration difference created in the epidermis, even though the blood stream's dermal concentration is extremely low.[2]

c) Hypodermis

The dermis and epidermis are supported by the hypodermis, sometimes referred to as subcutaneous fatty tissue. It is used to store fuel. These layers give general protection, nutritional support, and temperature management. It may contain cells that are sensitive to pressure and carries major blood vessels and nerves to the skin.[2]

Film-forming systems (FFS) are an innovative way to administer drugs via the skin. It can solve the various drawbacks of current formulations, such as cream and patches. Patches have drawbacks, such as skin discomfort and the potential for sweat duct occlusion, which lowers patient acceptance. Creams have a low resistance to wiping off. This causes the drug's contact time at the application location to be inadequate. For topical and transdermal formulations, FFS can serve as a substitute. Here, a suitable solvent is used to dissolve the medication and film-forming polymers. These systems have the ability to release drugs over a long period of time and generate a thin film when applied to the skin. It has the benefits of both creams and patches.[3]

2. Advantages

- For those who are unable to take systemic medication.
- Greater increased dosage flexibility, improved patient compliance and aesthetic appearance.
- Preferred in early patients/patients receiving multiple medication to avoid drug interaction.
- The film forming gel formulation has prolonged contact time with the applied nail surface and has a controlled release of drug.[3]
- Improved adherence
- Film forming systems are simple and offer advantages of transparency, non-greasy and lower skin irritation.[3,1]

3. Disadvantages

- These formulations are having local side effects such as periungual erythema and proximal nail fold erythema.
- Formed film may detach from the applied site if it is not protected properly.
- The therapy is longer, it takes longer time to cure disease of nail.[3]

4. Principles and working of film-forming systems

The medication and film-forming excipients are dissolved or dispersed in a volatile solvent or solvents to create FFSs. The liquid state of the FFS is determined by the solubility of the drug, excipients, or dispersions of encapsulated drug micro particles or nanoparticles in solvents. The solvents evaporate and combine with the excipients to form a film when they come into contact with the skin. After the film is produced, the medicine is released gradually by the polymer matrix that contains it, much like a patch. To regulate systemic or local effects, drug doses in a film-forming formulation can also be changed based on the volume of solution each spray. Additionally, an FFS guarantees the efficient and equitable distribution of medications. Ease of use can also improve patient compliance. (1) Fig. 2 illustrates the concept.

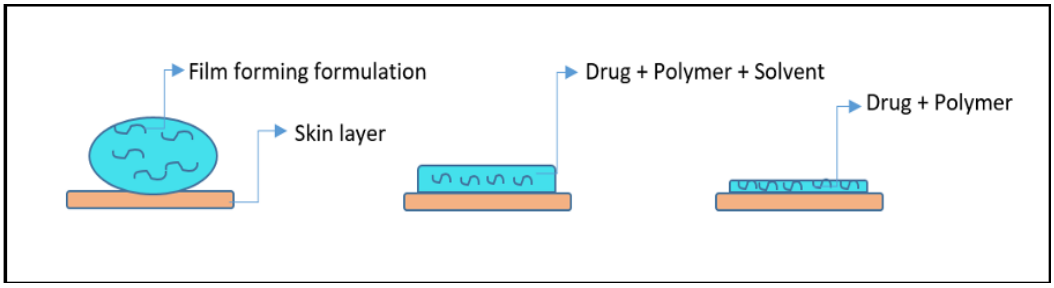

Fig. 2: Principle of film forming systems.

5. Mechanism of film forming System

A FFS is a topical drug-delivery system in which a liquid solution (or suspension) is sprayed on the therapeutic site and, upon contact, forms a thin polymeric film. In this system, polymers act as a matrix that solidifies into a film on the skin or wound surface.[6,7] Once the film is formed, drug release proceeds in a manner analogous to transdermal patches: the active compound diffuses out of the polymer matrix over time. Unlike traditional patches, however, FFS can conform to the micro-contours of the skin or wound bed, such as deep indentations or crevices, because the small droplets of sprayed solution spread evenly and fill these irregularities. This conformation can increase therapeutic efficacy and improve medication access to target tissues. Additionally, by changing the volume each spray, dosage can be adjusted, providing flexible control over either local or systemic medication effects.[6]

Because the sprayed solution forms a uniform, thin film throughout the application area, FFS further enhances drug distribution uniformity. Better patient compliance is a result of its simplicity of use.[6] It is more comfortable to remove the film with water after use than to remove more adhesive systems like patches.[7]

The thin, non-sticky quality of the FFS film lessens discomfort, particularly during movement, when compared to semi-solid topical treatments like gels or ointments. Furthermore, because the film is relatively permeable to moisture, wound exudate or skin moisture can pass through more readily, helping to maintain a balanced wound environment.[8] This moisture balance is important: in patches, for instance, excessive occlusion can lead to maceration or infection, but FFS offers a more breathable alternative.[2]

6. Components of Film Forming System

1. Drug
2. Polymers
3. Plasticizers
4. Solvents

1. Drug

The medication must permeate into the stratum corneum, the skin's outermost layer, as it is applied. The stratum corneum, which is primarily lipophilic, acts as the skin's main barrier. As a result, a highly lipophilic medication is more effective than a hydrophilic one at penetrating the stratum corneum. Log P 7-8. Therefore, a medication with a log P greater than 2 is deemed appropriate and typically needs little to no penetration enhancer. Drug transport through skin is greatly influenced by factors other than lipophilicity, such as molecular weight and size. Effective skin penetration is possible for molecules smaller than 500 Dalton. Since crystallization must not happen after the volatile solvent evaporates, the medication must be sufficiently soluble in the non-volatile solvent. According to research, a formulation with dissolved API should keep its pH between 5 and 10. The pH of the composition must be within this range to avoid discomfort when applied topically because skin pH is close to 5.[1]

2. Polymers used in FFS

The effectiveness of FFS preparations is largely dependent on polymers. In addition to controlling drug release, polymers serve as the foundation for film

formation. Additionally, polymers can stop molecules from changing and forming unexpected crystals. When choosing polymers, general factors to take into account include stability, biodegradability, ease of washing away by water, and non-irritating qualities.[6]

The FFS employs a variety of polymers that can be used to construct these systems. To achieve the desired film qualities, these polymers can be used alone or in combination with other polymers that form films. They are mainly divided into two categories: A. Synthetic Polymers, B. Natural and Semisynthetic Polymers.[9]

The list of polymers along with their molecular weight and properties are mentioned in Table 1.[10]

Table 1: Film Forming Polymers.

Sr.No	Polymer	Type	Key Properties	Applications
1	Eudragit RS/RL	Synthetic polymer	Water-insoluble, controlled release	Sustained drug release
2	Hydroxypropyl methylcellulose (HPMC)	Cellulose derivative	Water-soluble, film-forming, non-toxic	Skin-friendly drug delivery
3	Polyvinyl alcohol (PVA)	Synthetic polymer	Good film-forming, flexible, water-soluble	Cosmetic and pharmaceutical sprays
4	Polyvinylpyrrolidone (PVP)	Synthetic polymer	Excellent adhesion, water-soluble	Fast-drying topical sprays
5	Sodium alginate	Natural polymer	Biocompatible, gel-forming	Wound healing and skin protection
6	Chitosan	Natural polymer	Antimicrobial, bioadhesive	Wound care and transdermal delivery
7	Carbopol	Synthetic polymer	Thickening agent, bioadhesive	Controlled release and skin retention
8	Ethyl cellulose	Semi-synthetic	Water-insoluble, film-forming	Moisture barrier and sustained release
9	Gelatin	Natural polymer	Biodegradable, flexible	Cosmetic and wound healing applications
10	Acrylates copolymer	Synthetic polymer	Water-resistant, flexible	Long-lasting cosmetic sprays

3. Plasticizers

In a film forming system, plasticizers are employed to increase the film's tensile strength and flexibility. (10) The plasticizer should have low skin permeability and be compatible with the polymers being employed. (11) Since the polymer controls the plasticizer's efficacy, no other rule can establish the concentration of plasticizers to be employed in FFS. Plasticizers will be employed in the appropriate quantity. The film becomes smooth but sticky when too many plasticizers are employed, while it becomes brittle and has poor skin adhesion when too few are used. (9) Glycerine, polyethylene glycol, sorbitol, dibutyl phthalate, propylene glycol, triethyl citrate, and other plasticizers are frequently utilized.[11]

Plasticizers enhance the following characters of the film: (1)

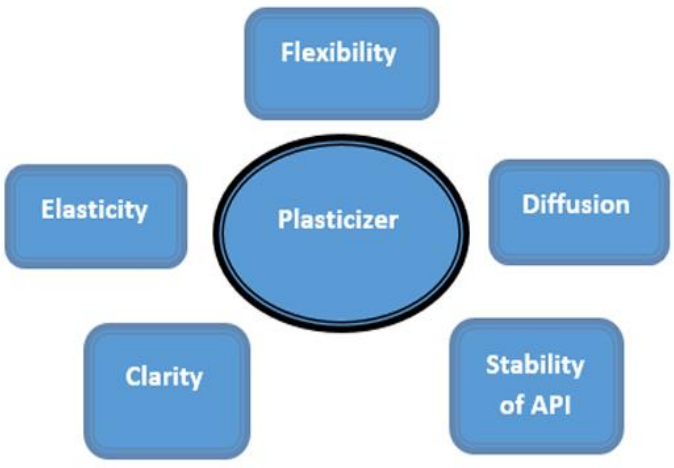

Fig. 4: Plasticizers enhance the above characteristics of the film characters of the film.

4. Solvents

Both volatile and non-volatile solvents are utilized in the FFS system. Balancing the film drying rate is the goal. Drug escape and penetration are hindered by films that dry up too rapidly and become rigid. To speed up the film drying process, the active ingredient is typically dissolved to saturation in the solvent.[6] The solvent is a crucial part of the film-forming system and does not end up in the film despite its quick evaporation. Only solvents with high solubilizing strength can change a drug's distribution to the skin. The solvent may have a direct impact on medication flow in addition to its indirect impact on penetration. Depending on the kind of solvent and its capacity to improve skin penetration, drug transport can be improved to varied degrees despite the brief period of skin contact.[12] Table 2 lists frequently used solvents for topical and transdermal use.

Table 2: Solvents used in FFS.

Sr. NO	Solvent	Key Properties
1	Ethanol	Fast evaporation, quick film formation
2	Isopropanol	Moderate evaporation, good solubility
3	Acetone	Very volatile, strong solvent power
4	Propylene glycol	Slows evaporation, improves flexibility
5	Water	Safe, balances irritation, slower drying

7. Different types of film forming formulations

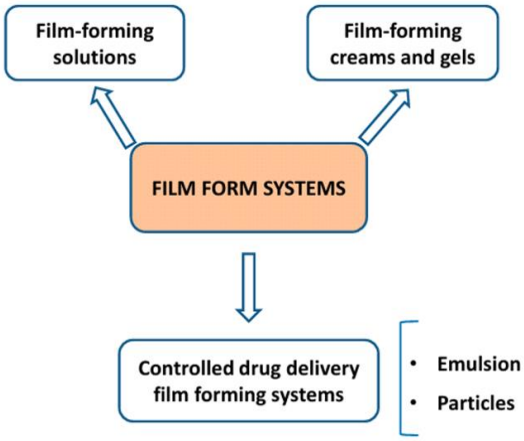

Fig. 5: Different types of film-forming formulations.

1. Film Forming Solutions

Film-forming solutions are the most common type of film-forming systems. As already described, the solutions mainly consist of a volatile solvent in which film-forming polymers are dissolved or dispersed, together with plasticisers, the drug, and other excipients. The evaporation of the volatile solvent creates a polymer film on skin surface.[4] Film forming solutions and sprays it is an attractive and novel approach in transdermal sustained drug delivery system. In this the polymeric drug solution is applied to the skin as a liquid/solution or sprayed on the skin and form as an almost transparent thin film by solvent evaporation.[8]

To ensure the polymer dissolves completely, the formulation preparation entails adding the polymer to the vehicle and stirring the mixture overnight. After obtaining a clear polymeric solution, further optional excipients like plasticizer or cross linker are added. The solution is agitated for twenty-four hours following the addition of all excipients. The polymers, such as polyvinyl pyrrolidone, polyethylene glycol, and hydroxyl propyl methyl cellulose, are selected to act as anti-nucleating agents and crystallization inhibitors, preventing drug crystallization even after solvent evaporation, for the physical stability of the API.[10]

An applicator can be used to apply film-forming solutions to the skin, which can then be left to dry. Film-forming spray is produced as a metered dose pump dispenser to deliver a predetermined dosage of medication, which is then sprayed onto the topical site to create a film. These technologies create an invisible, stable, quick-drying, non-irritating film from which the medication can be applied topically. As illustrated in Fig. 6, the film can be peeled off after delivery if the intended outcomes are achieved or for the duration of therapy.

Metered-dose spraying is one way to provide film-forming solutions. Numerous film-forming solutions are sold extensively. One of Eli Lilly's film-forming testosterone formulations, Axiron®, provides a sustained release of the hormone via the skin. Polyvinylpyrrolidone, a polymer, was used to make it. The solvents utilized were isopropyl alcohol and ethanol. (A)

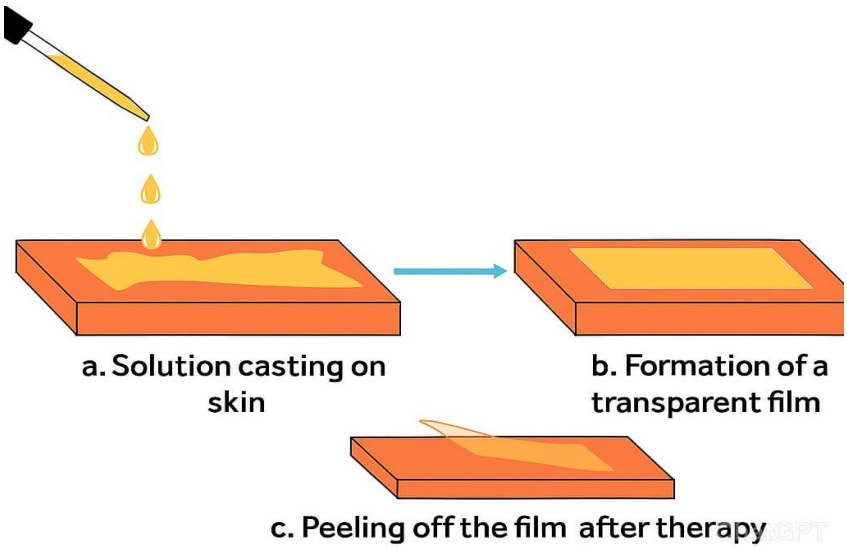

Fig. 6: Application of film forming solution on skin.

2. Film-Forming-Gels

Gels are visually appealing since they are typically translucent and colorless. As a semi-solid preparation, gels have the benefit of being simpler and more precise to apply than liquids. Because of their semi-solid nature, film-forming gel preparations are easier to apply than film-forming liquids. They are pliable and typically exhibit strong skin adhesion. The polymer matrix is more viscous than similar liquid preparations because of the additional gelling ingredient, which might be useful when creating sustained release dosage forms. Gels work especially well on mucosal membranes when compared to other semi-solid treatments.[4]

A semisolid dosage form with both liquid and solid components is called a gel. Immobilized within a three-dimensional network of interconnected solid components, the liquid component may be hydrophilic or hydrophobic. Aqueous gels with hydrophilic polymers that create three-dimensional networks in water are known as hydrogels.[10] Using polyvinyl alcohol, a skin-permeation enhancer, and an adhesive ingredient, Na-Mi et al. created a film-forming soft hydrogel for transdermal testosterone delivery in 2003. The gel's adhesive ingredient, polyisobutylene, was utilized to lower the surface energy and contact angle. After application, the gel was watched for two to three minutes to create a film, and the thin layer persisted for a day.[13]

3. Film Forming Emulsions

Emulsions are frequently utilized in pharmaceutical and cosmetic formulations, Because of their superior ability to solubilize lipophilic and hydrophilic active components and their acceptability in many applications, Oil and water make up the two phases of emulsions, which are liquid compositions. Since they are thermodynamically unstable, an emulsifier is typically used to stabilize them. One benefit is that the two-phase or multi-phase system can incorporate both lipophilic and hydrophilic medications. Because of its reduced viscosity, the emulsion is typically preferred by patients, making it crucial for aesthetic preparation.[1]

This kind of emulsion creates the continuous phase by dissolving or dispersing the utilized polymer in the volatile solvent. The polymer phase becomes more viscous as the solvent evaporates, stabilizing the inner phase. The dispersed phase droplets contain the active ingredient, which diffuses into the skin through the polymer matrix. The regulated sustained release of medications made possible by this in situ release is especially exciting for the creation of topical formulations for highly lipophilic medications with a strong affinity for the stratum corneum. When the solvent evaporates, the medication does not undergo supersaturation or crystallization because the active ingredient is localized in the dispersion phase. This is beneficial since crystallization would alter the emulsion's thermodynamic characteristics and perhaps reduce its stability.[4]

Using Eudragit NE and RS 30D as film formers, Lunter et al. created film forming emulsions for long-term cutaneous administration of nonivamide. The in vitro skin penetration and permeation of nonivamide from the produced film-forming emulsions was investigated in a different investigation by Lunter et al. It was discovered that diffusion via the polymeric matrix in which the droplets were placed controls the rate at which the active ingredient permeates. As a result, effective API concentrations in the skin and steady penetration rates could be sustained for a duration of 12 hours.[10]

7. Evaluations of the Film Forming System

1. pH

To increase the stability of the active ingredient or make it appropriate for the application site, the pH value is measured and modified. Diabetic wounds have a pH between 6.5 and 8 for skin pH between 4 and 6, while burns heal more quickly below pH 7.32. The

preparation's pH adjustment attempts to avoid irritation and modifications to the wound's physiological state during the healing process.[6] Additionally, the pH value of the dosage can influence how well pharmaceuticals penetrate the skin, depending on the degree of ionization. (A)

2. Viscosity

For the film-forming solution to be spreadable, viscosity is a crucial factor. The viscosity must be at its ideal level for good spraydability.[1] The type and attention of the polymer will affect its density. This is a crucial feature, especially in MDS, as the spreadability of the film forming product will depend on its density.[9] A Brookfield viscometer (DV-II, LV model, Brookfield, WI, USA) with a ULA-S00 shaft and a small volume connector with a bottle expressing water coat was used to measure the thickness. A ULA chamber was filled with 20 mL of the example, and the shaft was rotated at a speed of 10 rpm at 25 1 ◦C. Prior to the estimation, the examples were equilibrated for ten minutes. Additionally, the instrument was equipped with a temperature control unit. For each detail, an average of three readings were obtained.[19]

3. Film's tensile strength

The film's capacity to tolerate applied pressure is known as its tensile strength (TS). The purpose of TS testing is to determine whether the final film is flexible enough to follow the movement of the skin without cracking and resistant to abrasion. The following formula can be used to calculate it

$$TS = \frac{FM}{L \times W}$$

Where,

L is the film's thickness

Fm is the maximum pressure that can be held by the film before tearing,

W is the initial width of the film.

After stretching elongation which describes the elasticity of the film can be can found by formula given below.

$$EB = \frac{lmax\text{-}l_0}{l_0}$$

Where, lmax is the length of the film before the film is torn when pulled and

L0 is the initial length of the film.[1,3]

4. Film formation

The films are created on an excised pig ear skin or in a petri dish. With or without precipitation of the film-forming polymer, film-formation is assessed and graded as complete and uniform, incomplete or non-uniform. The films' aesthetic qualities are described as sticky or dry, transparent or opaque, and peelable or non-peelable.[10] The visual characteristics of the film are characterized as sticky or dry, opaque or transparent, and peelable or not. Film flexibility is based on the examination of skin attachment and cracking, which can be done by stretching the skin in two or three different directions. The film is considered flexible if there is neither skin fixation nor cracking; if both are present, it is considered non-flexible.[9]

5. Film flexibility

Stretching the skin in two or three directions allows for the evaluation of film flexibility based on the reaction of skin cracking and skin fixation. If there is no skin attachment or cracking, the film is regarded as flexible; if there is, it is rated as non-flexible.[17]

6. Stability studies

Five sprays performed stability studies and were stored for three months. According to ICH guidelines, the formulations were placed in close-lid APF containers in the following circumstances: 30°C±2°C and 75±5% relative humidity. Samples from all sprays were taken at 0 and 3 months to get preliminary data on appearance, pH, and viscosity.[16]

7. Stickiness

Cotton wool is used to gently press the dry film. The quantity of cotton wool fibers adhered to the film determines its viscosity. If the attached fiber is thick, the film adhesiveness is deemed high; if it is thin, it is deemed medium; and if there is little to no attached fiber, it is deemed low. In order to determine whether the film will readily adhere to clothing or other items while in motion, stickiness is tested.[6]

8. Spray angle, pattern and droplet size distribution

Using paper sprayed with pointer reagents makes it simple to see the shape of the spray arrangement. Here, the key elements are the pH of the film-shaping configuration and the type of dissolvable. The design and shower bead measure delivery will be more transparent if a solvent-sensitive substance is used. The splash point and secured range are then determined by measuring the design's width.

$$\text{Spray angle } \theta = \tan^{-1}(l/r)$$

Where r is the circle sweep and l is the removal of the paper surface from the spout. The spout is typically 15 cm away from the paper. The spreading of the film-forming arrangement during a shower is more problematic at higher shower points. Figure 7 shows an outline of the estimated shower design.

The shower design is examined at 600x600 dpi (Konica Minolta scanner, bizhub c3350) to determine the secured range. At that moment, the image is transformed into a double image using the imageJ software. The following equation is then used to determine the secured region's rate.

$$\%scope = \text{Zone secured (white pixel)} / \text{Region secured (dark pixel)} \times 100\% \quad (5)$$

The molecular investigation plugin for the ImageJ software is used to measure the beads. You can also use

Spraytec®, a product of Malvern (Malvern, UK), which functions on the principle of laser diffraction. Bead distance across is measured in millimeters (mm), from which D10%, D50%, and D90% are calculated. The consistency of the bead estimate conveyance is then ascertained by computing the relative span calculate (RSF) using the following formula.[20]

RSF = D90% - D10 % / D50%

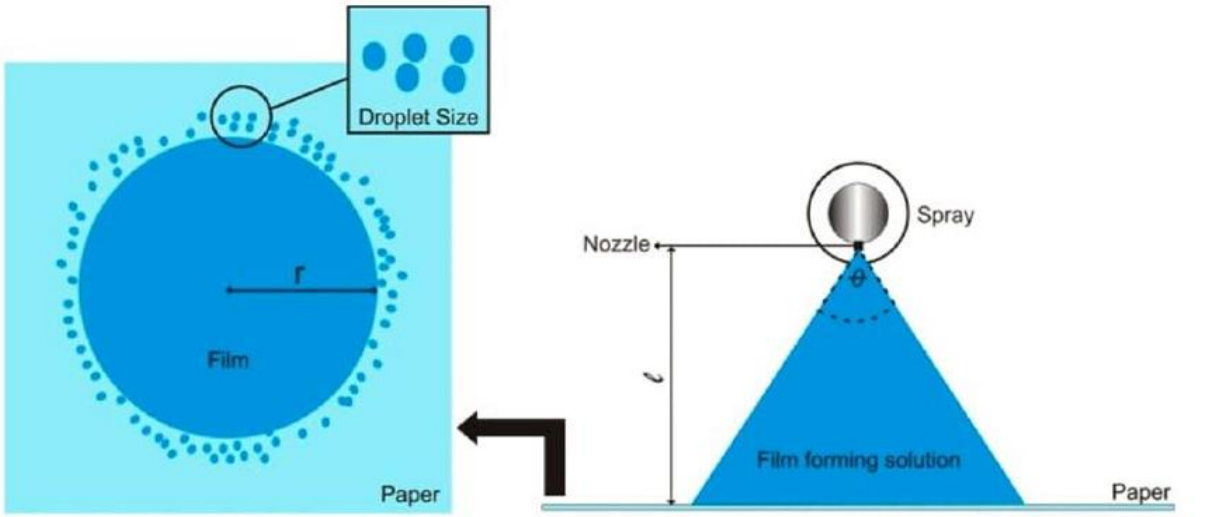

Fig. 7: Measurement of spray angle.

9. Drug content

A beaker filled with 50 milliliters of methanol was sprayed with the mixture. 100 milliliters of methanol were added after 10 minutes of shaking. A UV spectrophotometer was used to determine the concentration after 10 ml of the solution was added, filtered, and the amount of dissolved drug was measured.[12]

10. Moisture content

To identify the precise drying time and mark the conclusion of the film's production process, the moisture content of the created film is assessed. Humidity is studied using pharmacopoeia techniques (gravimetry) and readily available equipment (moisture meters, humidity analyzers). For identifying the end of film formation, a stickiness test might also be regarded as practical and economical. A separation test is suggested by certain writers (Kathe and Kathpalia, 2017). If cotton wool is added to the film, the cotton wool fibers will disappear throughout the drying process. This shows that the film has solidified at last. Moisture assessment is achievable in dynamics because excessive drying of the film can result in loss of elasticity and harm to the damaged skin by solid film particles.[15]

11. In vitro Drug Penetration/Release Study

Franz diffusion cells are typically employed as compartment separators in this test utilizing cellulose membranes (pore size 0.45 µm), nylon membranes (pore size 0.22 mm), or silicone membranes. Phosphate buffer (pH 7.4) is the media utilized. The donor compartment is filled with the film-forming solution once the compartment system is prepared. An equipment is used to measure the solution that diffuses into cells at predetermined intervals. Following sample collection, the same volume of fluid is replaced.[6]

12. Ex vivo permeation study

The purpose of the ex vivo permeation studies is to investigate how the skin barrier affects the developed film forming mechanism. Permeation studies can be conducted using Franz diffusion cells or Keshary-Chien diffusion cells. *Rat* skin is positioned between the two compartments, with the dermis facing the receptor compartment and the stratum corneum facing the donor compartment. When the formulation is applied to the skin's surface, it dries and forms a film. Phosphate buffered saline (pH 7.4) kept at 37°C and 0.5°C is found in the receptor compartment. Aliquots are gathered at predetermined intervals and examined using an appropriate spectroscopic technique.[17]

8. Marketed Film-Forming Sprays (FFS) and Their Applications

Product Name	Drug / Active	Company	Application / Use
Axiron®	Testosterone	Eli Lilly	Transdermal testosterone therapy
Lamisil Once®	Terbinafine HCl	GSK Consumer Healthcare	Topical antifungal (tinea pedis)
Medspray® (Patch-in-a-Can)	Terbinafine HCl	MedPharm Ltd.	Antifungal spray-on system
Hansaplast® Spray Plaster	No drug (protective film)	Beiersdorf	Wound protection

9. Applications of Film-Forming Sprays

1. Wound Healing / Treatment of Skin Injuries

- Film-forming sprays are used for treating wounds (like surgical incisions, burns, or diabetic wounds). The formed film maintains moisture, which can accelerate wound healing, and provides a barrier to protect the wound.[22]
- The thin film can deliver the drug in a sustained manner, reducing the need for frequent reapplication.[6]

2. Controlled / Sustained Drug Release (Topical and Transdermal)

- FFS can act like a "drug reservoir" on skin: once the film is formed, the drug is released gradually over time.[13]
- Because the film adheres well, it prolongs the contact of drug with skin, improving bioavailability.[22]
- The polymer matrix (natural or synthetic) can be chosen to tune how long the film stays and how fast the drug diffuses.[6]

3. Local Anesthetic / Pain Management

- Example: A metered dose film-forming spray of ropivacaine, a local anesthetic, was developed for topical pain relief.[22]
- This helps concentrate the drug in skin layers and reduces systemic side-effects (since drug remains localized).[22]

4. Anti-Inflammatory / Phytoconstituent Delivery

- Curcumin (a natural anti-inflammatory compound) has been formulated into a film-forming topical spray to improve patient comfort, adherence, and sustained delivery.[22]
- Such sprays can improve permeation and drug retention compared to conventional creams.[22]

5. Antifungal Therapy

- Film-forming sprays have been studied for delivering antifungal agents in a more efficient way: the film helps maintain drug contact, improves local drug concentration, and reduces systemic exposure.[6]
- Because the spray forms a film, it can act like a depot of antifungal drug, sustaining its presence on the skin for prolonged effect and possibly reducing the frequency of application.[10]
- The polymer and solvent systems in these sprays can be selected to enhance the sprayability, drying time, flexibility, and film adhesion, which are critical for effective antifungal therapy.[6]

6. Improved Patient Compliance and Cosmetic Acceptability

- Compared to traditional semi-solid formulations (creams, ointments), FFS are more aesthetically acceptable: they form transparent, non-greasy films.[10]
- Because of the in situ film formation and long residence time, FFS reduce the need for frequent reapplication, improving patient adherence.[22]
- The quick drying time, non-stickiness, and flexibility of the formed film make FFS comfortable for users.[13]

7. Smart / Responsive Drug Delivery

- Advanced FFS research explores "smart" polymers for example, pH-responsive or biodegradable polymers to make the film sensitive to wound conditions or skin environment, thus offering tailored drug release or biodegradation.[13]
- Nanoparticle-based carriers (e.g., liposomes, polymeric nanoparticles) can be embedded in film-forming sprays to protect sensitive biomolecules (like growth factors) and provide more controlled release.[13]

8. Barrier / Protective Film Applications (Non-Drug)

- Apart from drug delivery, FFS can act as "protective" or "cosmetic" films: the polymeric film itself can serve as a semi-occlusive barrier, preventing contamination, reducing water loss, or shielding damaged skin.[13]
- In wound care, such protective FFS can serve as temporary dressings, especially for minor wounds or burns, combining barrier function with potential therapeutic agents.

10. Future Prospects

Film-forming sprays (FFS) hold strong potential for future advancements in topical and transdermal drug delivery. Ongoing research is expected to focus on developing smarter polymer systems that respond to environmental triggers such as pH, moisture, or temperature, allowing more precise and individualized drug release. Incorporation of nanotechnology such as nanoparticles, liposomes, and nanoemulsions may further enhance drug stability, penetration, and controlled delivery. Future FFS could also integrate biologically active compounds like peptides, growth factors, or herbal actives for improved wound healing and dermatological treatments. Advances in spray technology may lead to more accurate dosing, improved spreadability, and enhanced user convenience. Additionally, expanding clinical studies will be essential to validate safety, efficacy, and long-term performance, encouraging wider acceptance and commercialization. With continued innovation, film-forming sprays are likely to evolve into versatile, patient-friendly systems capable of addressing unmet needs in dermatology, pain management, infection control, and chronic disease therapy.

CONCLUSION

Film-forming sprays represent a promising advancement in topical and transdermal drug-delivery overcome many

limitations of traditional formulations such as creams, gels, and patches. By forming a thin, flexible, and adherent film on the skin after solvent evaporation, they systems offer improved drug residence time, enhanced permeation, sustained release, and superior cosmetic acceptability. Their ease of application, transparency, non-greasy nature, and reduced risk of irritation contribute significantly to better patient compliance. Although current marketed products are limited, research demonstrates strong potential for FFS in areas such as wound healing, antifungal therapy, pain management, and protective barrier applications. With continued formulation optimization and clinical evaluation, film-forming sprays are poised to become an effective and patient-friendly alternative for delivering a wide range of therapeutic agent.

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