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Review Article

Comparative And Critical Review Of Natural And Synthetic Polymers Used In The Transdermal Patches Of Matrix Type: Recent Advances And Future Directions

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ABSTRACT

Transdermal drug delivery system (TDDS) has gained a cool spot among oral and parenteral routes as it allows us some form of steady dose release without incurring first pass effects through the liver. Especially matrix type patches because of the simple build, low costs, and the way they deliver drugs over a predictable, extended period of time. Polymers play a massive role here they determine the strength of the patch, the diffusion of drugs, the stability, and the overall outcome (therapeutic) of the treatment. This review brings together comparative and critical review of natural and synthetic polymers used in the matrix patches. Natural polymers like Chitosan, Guar gum, Xanthan gum, Alginate, Gelatin - The possibility to study natural choices, renders them a lot: they really are biodegradable, biocompatible and eco-friendly. Though they can vary in each batch and are sensitive to moisture and sometimes don't have enough mechanical strength to them. On another side, synthetic polymers, like hydroxypropyl methylcellulose, polyvinyl alcohol, polyvinylpyrrolidone, ethyl cellulose, and Eudragit have greater reproducibility and are structurally sound and more capable of controlling the release rate. We also dig into recent advancements such as polymer blending, nanoEnabled matrices, bioadhesive systems and polymers which are stimuli reactive to enhance the transdermal performance on the development of innovative and sustainable matrix based transdermal systems are also covered in this review.

INTRODUCTION

Transdermal drug delivery systems (TDDS) are a newer technique they allow us to regulate and maintain the exposure of drugs throughout the system via the skin [1]. Oral routes are often subject to firstpass metabolism, breakdown in the stomach, and fluctuating plasma levels-all components that may cause a lower well-being of the drug as well as patients not taking it

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consistently. TDDS avoid these problems by evading liver metabolism and providing constant plasma concentrations over an extended period of time. That's why they're becoming the best option in the treatment of chronic conditions such as heart diseases, neurological problems, and inflammatory diseases [2].

Of all the transdermal methods, those of the matrix type are the most studied and commercially viable. In a matrix system, the drug is uniformly distributed in a polymer matrix and the drug release is regulated by the diffusion through the polymer matrix. In comparison to reservoir systems, matrix patches are structurally simpler, minimize risk of dumping of the dosage, and they are cheaper to produce using methods such as solvent casting [3]. Recent formulation studies demonstrate that matrix patches are able to provide sustained predictable release profiles, typically data conforming to diffusion-controlled kinetics and described by equations, such as Higuchi and Korsmeyer-Peppas. These results mark the importance of polymer selection and matrix design when releasing drugs.

The patch's polymer composition is an important factor in determining mechanical strength, flexibility, moisture absorption, drug stability, and permeation. Hydrophilic polymers such as hydroxypropyl methylcellulose and polyvinyl alcohol swell with the addition of water and therefore form a gel, which regulates the diffusion of the drug. Hydrophobic polymers e.g. ethyl cellulose and eudragit act as diffusion barriers to prolong the release and enhance the mechanical integrity [4]. Blending hydrophobic and hydrophilic polymers has shown to be a good strategy to obtain optimal release kinetics with a sufficient tensile strength and flexibility.

Natural polymers - chitosan, guar gum, xanthan gum and sodium alginate have seen an upsurge in recent years thanks to their biodegradability, biocompatibility and environmental friendliness. However, they are potentially variable in physicochemical properties and sensitive to the environmental conditions. Synthetic polymers, on the other hand, are reproducible, quality-assured and approved, yet have sustainability concerns. Despite the many individual studies conducted on different systems of polymers, there hasn't been a fullportrait of a comparison between natural and synthetic polymers in matrix type transdermal patches. Therefore, this review will critically discuss the roles, benefits and limitations of both types of polymers to support rational design and consideration of matrix-based transdermal drug delivery systems [5].

Basic Principles of Transdermal Patches of the Matrix Type

Matrix-type transdermal patches form one of the most strongly studied platforms in the transdermal drug delivery system , due to their structural simplicity and ability to modulate the rates of release [1]. In those kinds of systems, the pharmaceutical agent is either homogeneously dispersed or dissolved in a polymeric network that simultaneously provides a drug reservoir and a release barrier. This network consists of one or more polymers that can be hydrophobic, hydrophilic or a mixture of both, plasticizers, permeation enhancers and backing membranes [2]. Solvent casting techniques are the most popular fabrication method used; this method allows for fabrication of flexible, uniform films with a uniformly dispersed drug. The mechanical properties of the patch , such as tensile strength, elongation, folding endurance and moisture resistance are much determined by the

composition of the polymer and concentration of plasticizers.

The general mechanism of drug release from matrix-type patches is diffusion control. Upon application to the skin the drug diffuses from the polymeric matrix to the patch surface, onto

the stratum corneum and finally into the systemic circulation. Hydrophilic polymers may expand in the presence of moisture creating aqueous pores for diffusion; hydrophobic polymers will not diffuse much and will increase the release times [3]. The Higuchi model has been found to be the most suitable for the description of square root of time diffusion kinetics in matrix systems in several experimental investigations [4]. In some cases, anomalous (non-Fickian) behaviour of transport has been observed and described by means of Korsmeyer-Peppas modelling, in which diffusion and polymer relaxation play a role in the release process [5]. Consequently, the choice of polymer type, matrix architecture and drug-polymer interactions plays a major role in determining the release mechanism of the drug as well as the overall therapeutic outcome.

Matrix type patch has a lot of advantages in terms of safety, manufacturability and stability compared with reservoir system. Reservoir designs incorporate a separate compartment for the drug, and a rate controlling membrane, thereby complicating the design and also operates with the chance of dose dumping in case of membrane failure. In contrast, matrix systems remove the separate reservoir layer, which simplifies production and increases the mechanical strength [6]. They are usually thinner, more flexible and less expensive to manufacture. Furthermore, the homogenous distribution of the drug in the polymer matrix reduces the possibility of a sudden release of the drug, thus enhancing the safety and reliability of the patient. These attributes form the basis of the widespread popularity of the matrix-type system in the research of transdermal formulations at present.

CLASSIFICATION OF POLYMERS :

Polymer Category	Examples	Characteristics	Role in Matrix Patch	Limitations
Natural Polymers [1,2]	Chitosan, Guar gum, Xanthan gum, Sodium alginate, Gelatin, Pectin	Biodegradable, biocompatible, eco-friendly, hydrophilic, moderate swelling and bioadhesive	Formation of gel-like matrices on hydration, diffusive drug release, increased dermal adhesion	batch-to-batch variability, sensitivity to moisture, comparatively lower mechanical robustness, difficulties in stability
Synthetic Polymers [3,4]	Hydroxypropyl methylcellulose (HPMC), Polyvinyl alcohol (PVA), Polyvinylpyrrolidone	Reproducibility in properties, superior mechanical strength,	Regulation of drug diffusion, provide	Limited biodegradability, environmental concerns, potential

	(PVP), Ethyl cellulose, Eudragit (RS/RL), Polyethylene oxide	chemical stability, swelling.	mechanical integrity and flexibility, provide sustained and predictable release profiles, etc.	need for plasticisers in some grades
Semi-Synthetic Polymers [5,6]	Cellulose derivatives (HPMC, HPC, CMC), Modified starch derivatives	Modified starch derivatives chemically modified natural polymers imparting improved solubility and film-forming ability, with a balanced level of hydrophilicity	Provide controlled swelling; improve film strength; optimize release profile when blended with other polymers	Moderate moisture sensitivity and elevated cost in comparison to natural polymers

Natural Polymers in Matrix type Transdermal Patches

Natural polymers have recently emerged as a promising alternative to conventional types of matrixes including transdermal patches, and their characteristics of biodegradability, biocompatibility, low toxicity and renewable origin. Recent formulation studies have shown that natural polymers can be successfully used as matrix formers, release modifiers and bioadhesives in transdermal systems.[1,2] They are highly hydrophilic and thus are able to swell when they become hydrated so as to form a three-dimensional network and control the diffusion of the drug. Although synthetic polymers currently dominate the market, there has been an increased interest in green chemistry and sustainable pharmaceutical development, leading to investigation of the use of plant and animal - derived polymers for matrix - type patch design.[3]

Natural Polymers

Chitosan

Chitosan is among the most well researched natural polymer for transdermal applications. It is a cationic polymer in nature derived from chitin; it possesses many film-formation, bioadhesive, and permeability-enhancing properties, making them most suitable for the use of matrix patches.[4] Chitosan interacts electrostatically with negatively charged constituents of skin that temporarily opens up the tight junctions, thereby achieving increased drug permeability. Experimental data suggest that the drug release property of chitosan-based matrix patches shows a controlled drug release pattern and swelling behavior that generally follow a diffusion dominated behavior. Yet, it may have a low mechanical robustness, which may require the use of other polymers as a blend to ensure an optimal functionality.

Guar Gum

Guar gum is a galactomannan polysaccharide isolated from Cyamopsis tetragonoloba which is very viscous and has good swelling characteristics in aqueous solution. Within matrix-type patches, the addition of guar gum is involved in the formation of a gel and in the modulation of the drug diffusion, in the form of a hydrogel layer.[5] Studies indicate that as the concentration of guar gum is increased, the matrix density and viscosity are increased and hence the time of drug release also increased. Nevertheless, if the swelling is excessive, it may affect the structural integrity and it is then necessary to introduce synthetic polymers to enhance mechanical strength.

Xanthan Gum

Xanthan Gum is a microbial polysaccharide produced by Xanthomonas campestris which is used extensively for its superior thickening and stabilizing properties. It increases the viscosity of the matrix and eases the distribution of the drugs.[6] Its hydrophilic nature encourages release mechanisms that are governed by swelling. Xanthan gum patches have prolonged releasing characteristics; however, sensitivity to moisture, as well as declining tensile properties may make it unsuitable for use as a normal.

Sodium Alginate

Sodium alginate is a linear polysaccharide containing the manifold acid and mannuronic acid residues obtained from brown algae. It forms hydrogels that are hydrated and cross-linked in the presence of divalent ions and hence increasing structural stability.[7] Controlled drug diffusion and swelling are attained by alginate matrices. The early burst release may occur if the rapid hydration is not optimized based on formulation parameters.

Gelatin

Gelatin, a protein product from collagen is cherished for its biocompatibility as well as its ability to form films. In the case of matrix systems, the gelatin provides flexibility as well as enhances the patch adhesiveness.[8] It forms thermo-reversible gels making diffusion-controlled drug release facilitating. However, longer, gelatin-based formulations can be sensitive to humidity and temperature variables which would affect long term stability.

Physicochemical characteristics

The performance of natural polymers in matrix type transdermal patches critically depends on physicochemical factors like molecular weight, swelling index, viscosity, solubility and film forming capability. Most natural polymers are hydrophilic in rechargeable water that generate a hydrated gel layer under the influence of moisture, leading to a high swelling and is the regulator of drug diffusion.[2,5] Swelling behavior is critical in determining release kinetics and mechanical integrity.

Natural polymers typically have favorable bioadhesion properties because they contain functional groups such as hydroxyl, carboxyl and amino groups, which contribute to the improvement of interactions with the skin surface.[4] Nevertheless, they can have lower tensile strength and higher moisture absorption compared to synthetic polymers, but the effect of these characteristics on storage stability and reproducibility must be determined.[3] Integration of natural with synthetic- or semi-synthetic-polymers has often been documented as a measure to strengthen mechanical effectiveness with biocompatibility.[6,9]

Drug Release Behavior

Drug release from natural polymer-based matrix patches is mainly affected by diffusion and swelling phenomena. Upon application the polymer matrix swells with moisture from the skin and aqueous channels are formed causing diffusion of the drug molecules.[1,7] Most studies report the release kinetics according to the Higuchi equation and thus it is suggested that the release is diffusion controlled, as is the case for a few systems which exhibit anomalous transport behaviour using the Korsmeyer-Peppas equation.[5,10]

Polymer concentration, cross linking density, solubility of the drug, and matrix porosity altogether play a role in determining the rate of release. Increased polymer concentration normally increases the matrix viscosity and so lowers the rate of drug diffusion. On the contrast , low polymer content may lead to faster release and burst release. Research has shown the ability of natural polymers to achieve sustainable release profiles comparable to synthetic polymers providing that they are optimized particularly well.[8,9] .non-uniformity of natural polymer composition can affect reproducibility and scalability.

In sum, natural polymers are a promising route for matrix-type transdermal patches owing to their safe use, sustainability and ability to provide a wide range of functions. Nonetheless, issues such as mechanical strength, moisture sensitivity, and uniform are problems that need to be overcome by careful formulation development and polymer blending strategies.[3,10]

Advantages

Natural polymers have biocompatibility and generally a low significant toxicity, thus allowing long-time applications to the skin.

They are environmentally benign and biodegradable, easily overcoming the sustainable development of pharmaceutical formulations.

Their inherent adhesiveness promotes deemed contact with skin and may supplement drug permeation.

Hydrophilic natural polymers swell during hydration, thereby creating an environment for diffusion-controlled drug release of active substances.

Certain naturally occurring polymers, such as the polymer chitosan, have been shown to increase transdermality through an interaction with the Stratum corneum.

They are cheap and can be drawn from renewable resources in significant quantities.

Disadvantages

Natural polymers are prone to batch-to-batch variation due to variation in biological source and extraction methodology.

Their mechanical strength is generally poor if compared with the synthetic counterparts thereby compromising the patch durability.

High moisture sensitivity can have a negative impact on stability and release profile of therapeutics.

Inadequate handling and preservation of food is a risk factor for microbial contamination.

Environmental factors, such as humidity and temperature may affect their physicochemical stability.

Synthetic Polymers in Matrix Type Transdermal Patches

Synthetic polymers are mainly used in transdermal patches with matrix due to their reproducibility, mechanical strength and control over the drug elution (1,2). These materials have predictable performance, uniform physicochemical properties and well-defined macromolecular architecture, making them favourable for large scale manufacturing of pharmaceuticals. Over the last ten years, many investigations on the formulation of medication have examined the use of synthetic polymers, individually or in combination, to optimize the kinetics of drug release, or patch integrity and stability (3).

HPMC

Hydroxypropyl methylcellulose (HPMC) is considered to be a choice cellulose derivative. It is one of the most widely used synthetic polymers in the matrix formulations (4). HPMC has excellent film-forming properties, hydrophilicity and swelling properties that all promote sustain release of medication. Hydration of HPMC forms a gel layer that controls the diffusion of drugs, further increases HPMC concentration causes increased viscosity of the matrix and thus increases the diffusion way, reducing the rate of release. Its tendency to interact with a range of drugs and plasticisers in intermolecular complexes makes it an ideal matrix former for use in a transdermal product.

Ethyl Cellulose (EC)

Ethyl cellulose is a hydrophobic polymer and is commonly used as a release retardant in matrix systems.5 Its low aqueous solubility decreases diffusing ability of drugs and slows down the release time. EC also increases the mechanical strength and low sensitivity to moisture. Hydrophilic polymers are typically incorporated with EC, such as HPMC, to provide simultaneously balanced release kinetics as well as structural stability.

Eudragit

Eudragit polymers (e.g. RS and RL grades) are copolymerised methacrylates that are characterised by controlled permeability (6). The scale of this porosity and the rate of diffusion out of the matrix can be modulated by them to allow sustained drug release. The RL grade has better permeability than RS which allows for an increased rate of release of drugs. However, their chemical stability and film forming ability make them suitable for long-lasting transdermal systems.

Polyvinylpyrrolidone (PVP)

PVP is a water-soluble polymer that is normally used in improving the solubility of a drug and achieving homogenous dispersion in the matrix (7). By introducing increased drug-polymer interactions, PVP can help to increase the rate of drug release owing to its hydrophilic nature. Excessive concentration however could lead to excessive moisture uptake and then hydrophobic polymers are required for integration.

Polyvinyl Alcohol (PVA)

PVA is a flexible, high tensile plastic polymer with excellent film forming properties (8). It contributes to its mechanical stability and elasticity of patch. When used in combination with other polymers, matrices made from PVA are known to have diffusion release of drugs and structural reinforcement.

Mechanical and Release Characteristic

The choice of the synthetic's polymer affects properties like tensile strength, elongation at break and folding endurance and moisture resistance

(2,5). Hydrophobic polymers (EC and Eudragit) increase the structural rigidity and reduce moisture uptake, and hence the storage stability. On the other hand, the hydrophobic polymers (SPE, pectin and chitosan) would decrease the swelling and reduce the diffusion of drug.

Drug release from synthetic polymer-based matrices occurs mainly by diffusion. The release behaviour is often associated with Higuchi kinetics, implying that a proportionality between cumulative drug release and the square root of time holds (9). In other systems non-Fickian (anomalous) transport have been observed implying a mixture of both diffusion and polymer relaxation mechanisms. Polymer blending is a popular technique to optimise the release profile and obtain a specific therapeutic response (3).

Advantages

Manufacturing processes for synthetic polymers are carefully controlled, and therefore reproducibility and quality are high [1].

They have higher mechanical strength and durability than most natural polymers.

The well-defined chemical structures of synthetic polymers ensure predictable kinetics of drug release and the ability to meet regulatory requirements.

Furthermore, the production of synthetic polymers can be easily up-scaled and industrialized, which improves their utility in commercial based transdermal products [6].

Disadvantages

Although synthetic polymers have numerous advantages, most are non-biodegradable and could be a cause of environmental problems [10].

Certain hydrophilic polymers have high absorption of moisture which may compromise stability.

Some synthetic polymers need the addition of plasticizers to provide the functionality of flexibility, thus increasing the complexity of the formulation.

Consequently, the cost incurred for the large-scale production of the synthetic polymers may be higher than that of some of the natural polymers.

Comparative Analysis of Natural vs Synthetic Polymers

Parameter	Natural Polymers	Synthetic Polymers
Mechanical Strength	Generally, have moderate to low mechanical tensile strength; possibly the need for blending to improve durability and flexibility, structural variability can impair mechanical consistency [1,2].	Provide better tensile properties, better elasticity and folding endurance and structural integrity consistent due to control synthesis [3].
Drug Release Control	Drug release is under the control of mainly the swelling and diffusion mechanisms; the variability in composition may have some	Provide diffusion-controlled release that is predictable and reproducible; polymer grade and concentration

	influence to the reproducibility of the release profiles [2,4].	provide a way to modulate the drug kinetics exactly [3,5].
Stability	Sensitive to moisture, microbial growth and environmental conditions effecting shelf life possible [1,6].	Chemically stable with lower susceptibility to environmental degradation ; generally, show an enhanced stability of storage [3,7].
Skin Permeation	Some polymers, such as chitosan, have bioadhesive and interaction properties with skin parts which enhance permeation and the swelling allows the diffusion [4,6].	Permeation can be controlled systematically by matrix density and polymer hydrophilicity, in which hydrophobic polymers will slow down the diffusion process while the hydrophilic types will facilitate the permeation [5,7].
Biocompatibility &Irritation Potential	Very biocompatible, biodegradable and related to low irritation potential, which are suitable for sensitive applications [1,4].	Generally safe and approved for pharmaceutical use however some formulations may cause mild irritation based on some additives and plasticizers [3,8].
Cost and Scalability	Often cost-effective and can be produced from natural sources but varies from batch-to-batch that may affect the production of this method to a larger scale [2,6].	Achieve good quality control; applicable to industrial manufacturing demands and regulatory compliance compared with potentially far greater cost [3,7].

POLYMER BLENDING IN THE MATRIX TYPE TRANSDERMAL PATCHES

Combinations of Naturally occurring and Synthetic polymers

The advantages of the polymer blending are widely exploited in the matrix forms of transdermal patches to include the desirable characteristics of natural and synthetic polymers while overcoming their respective shortcomings. By integrating biodegradability, bioadhesion and swelling mediated diffusion of natural polymers such as chitosan, guar gum, xanthan gum and alginate with the mechanical strength, stability and reproducibility of synthetic polymers such as HPMC, ethyl cellulose, PVA and Eudragit, synergy matrix structures are created which facilitate a controlled drug release and allow for maintaining of structural integrity [1,2]. For example, film-forming ability and controlled release are enhanced with chitosan-HPMC concurrent because of enhanced intermolecular interactions within the polymer network [3]. Similarly, guar gum and ethyl cellulose combination helps minimize uncontrolled swelling and early burst release leading to a less erratic drug release profile [4].

Effect on Release Kinetics

Polymer blending has a significant impact on the kinetics of drug release by affecting matrix porosity, swelling behavior and drug diffusion pathways. Hydrophilic polymers expand when they absorb moisture, by which aqueous channel is formed, which helps the spreading of diffusion, while hydrophobic polymers act as water-absorption barriers that retard diffusion [2,5]. Experimental investigations show that the kinetics of blended systems usually follow Higuchi kinetics pointing out a diffusion-controlled drug release [5]. In a few situations Korsmeyer-Jeffery (Peppas) modeling indicates the presence of anomalous (not Fickian) transport and therefore the existence of simultaneous diffusion and polymer relaxation processes as contributors to the release behavior [6]. The ratio of hydrophilic vs. hydrophobic polymer content plays a key role as high hydrophobic content will decrease rate of diffusion of drug whereas high hydrophilic content will increase rate of release of drug. As such, polymer blending provides the possibility to fine-tune the kinetics of release to maintain therapeutic plasma concentration over sustained time periods.

Through experimental observation, the mechanical properties were improved as measured by performance quantities. Among the most important advantages of polymer blending is enhancement of the mechanical properties of the patch. Natural polymers are usually brittle or mechanically-weak films, while synthetic polymers added greatly enhance tensile strength, elasticity and ability to fold [1,3]. For example, alginate/PVA blends have an improved flexibility and a better resistance to the cracking occurring in storage [4]. Blending also helps to improve the uniformity of the film and helps avoid the tendency to tear while applying the patches. These enhancements add to higher levels of patient comfort, durability and long-term stability of the transdermal system.

In conclusion, polymer blending is a logical and efficient strategy used for the development of matrix-based transdermal patches to provide controlled drug release features and mechanical properties without losing biocompatibility.

THE RECENT ADVANCES IN MATRIX TYPE TRANSDERMAL PATCHES, 2015-2025.

Nano-Enabled Matrix Systems

Current developments in transdermal patches in the form of matrices is increasing with the use of nanotechnology to monitor the drug permeation and obtaining controlled release. Polymeric nanoparticles, solid lipid nanoparticles, nanoemulsions and nanostructured lipid carriers have been used as additives, which are introduced in polymeric matrices in order to improve the solubility of poorly water-soluble drugs and their capacity to penetrate the skin [1,2]. These nanostructures are used to enhance drug dispersion into the matrix, improve the thermodynamic activity, and increase the transdermal flux. Empirical evidence has shown that better values of bioavailability and prolonged release results can be achieved when nanoparticles are homogeneously dispersed in hydrophilic and hydrophobic polymeric mixtures [3]. Consequently, nano-integrated matrices are associated with reduced dosing frequency and maximise therapeutic effectiveness as well as controlling diffusion kinetics.

Bioadhesive Polymers

The use of bioadhesive polymers has been investigated to increase the contact time with skin and drug penetration. Derivatives, such as

chitosan, carbopol, sodium alginate and polyacrylic acid, have high mucoadhesive and bioadhesive characteristics, which help to enhance the patch retention and reduce the detachment of the patches during application [4,5]. Recent designs involve bioadhesive natural polymers based in combination with synthetic film formers such as HPMC or PVA for an ideal balance of mechanical strength and adhesion. Increased adhesion shows higher absorption of drug and more stable plasma concentrations. Moreover, bioadhesive polymers can be used transiently to alter the stratum corneum so as to increase permeation without causing significant irritation [5].

Intelligent/ Stimuli-Responsive polymers

Smart or stimuli - responsive polymers are a key innovation in the transdermal administration of drugs. These polymers are responsive to environmental factors such as pH, temperature or ionic strength in order to control the release of the drug [6]. Thermoresponsive polymers, such as derivatives of poly(N-isopropylacrylamide) modified to change their swelling at specific temperature, exhibit the ability to tune the diffusion profiles of the drugs with signals from the microenvironmental environment (at the surface of skin) [7]. pH-responsive matrices change the swelling upon altering the pH that allows the drug to be released more or less precisely. Such systems are programmable or can be triggered at will which provide great therapeutic accurateness in chronic disease management.

Sustainability and Biodegradation of Polymers

Researches on matrix patches based on sustainable and biodegradable polymers increased with the environmental concerns being on the rise. Natural polymers, such as cellulose derivatives, starch-based materials, alginate and chitosan, which have the advantage of being renewable in nature and being environmentally benign degradation substances, are increasingly used [4,8]. Current investigations are focused in improving mechanical stability combining blending and crosslinking with biodegradability. Sustainable polymer systems have a lower environmental footprint and are more familiar to the patient because of their lower toxicity/irritation levels, which is aligned with the general trends toward green pharmaceuticals worldwide.

Issues and shortcomings of matrix type transdermal patches

Batch Variability of Natural Polymers

Natural polymers, such as chitosan, guar gum, xanthan gum, alginate and gelatin, have a wide range of molecular weight, viscous and chemical structure on different batches. This variability affects the mechanical characteristics, drug loading capacity, drug release kinetics and repeatability of patch performance (37, 38).

Stability Problems

Hydrophilic and bio-biased polymers are prone to moisture absorption, swelling and physical changes by water during storage, resulting in changes in drug discharge and material mechanical changes. In addition, some drugs may crystallize or degrade during storage in the matrix and their efficacy may be reduced over time (46, 47).

Future Directions

The future research must be to aim at:

1. Carrying out comprehensive head-to-head comparative investigations of natural and synthetic polymers, using standardized evaluation procedures that include mechanical

testing, release kinetics and permeation testing.
2. Conducting more clinical trials in order to confirm long term safety and therapeutic effect.
3. Exploring novel polymer blends aimed at enhancing mechanical robustness, stability and synergistic drug release profiles
4. Engineering intelligent, stimulus-responsive and nanostructurally optimized polymeric delivery vehicles.
5. Incubation of green pharmaceutical methodologies by focusing on the sustainable and biodegradable polymer materials.

CONCLUSION

Verily stunning promise has been seen within the use of matrix based transdermal patches for sustained and managed drug delivery using both natural and synthetic polymers. Natural polymers have biocompatibility and biodegradability while synthetic polymers have mechanical integrity and controlled release properties. However, some challenges persist such as batch-to-batch variance of natural polymers, stability issues, regulatory problems and lack of scale. Future investigations should perform thorough comparative evaluation, hybrid polymer systems and smart and stimuli responsive matrices as well as conduct clinical validation in order to move viable and efficacious products from laboratory prototypes to the marketplace. Integration of state-of-the-art polymer engineering, nanotechnology-enabled carriers and sustainable materials is expected to drive better performance of next generation transdermal platforms with superior therapeutic outcomes, patient adherence, as well as lower environmental impact.

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