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Original Article

Design, Development and Characterization of Transdermal Patch of Meclizine for Motion Sickness

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Abstract

The study aimed to develop and characterize a transdermal patch of meclizine for the treatment of motion sickness. Eight formulations were prepared and evaluated for drug content, thickness, weight variation, folding endurance, in vitro drug release, and patch adhesion. Among all formulations, MTP8 demonstrated superior performance, showing the highest drug content (99.5%), thickness (0.30 mm), weight variation (1.7%), folding endurance (335), in vitro drug release at 24 hours (71%), and patch adhesion (1.1 N/cm²). The findings suggest that MTP8 may be a promising candidate for a meclizine transdermal patch for motion sickness. Its high drug content and sustained drug release profile indicate potential for consistent and effective drug delivery. In addition, the patch's mechanical strength and adhesion properties suggest good durability and reliable skin adherence. Further studies, including in vivo evaluations, are warranted to confirm these results and to assess the safety and efficacy of the patch in clinical settings. In conclusion, MTP8 shows considerable potential as a transdermal patch for motion sickness, offering advantages in drug content, drug release, and overall patch characteristics. Future research should focus on optimizing the formulation and conducting clinical trials to validate its effectiveness and safety in the treatment of motion sickness.

Keywords: *Characterization; Design; Development; Meclizine; Motion Sickness; Transdermal Patch*

Introduction

Motion sickness is a condition characterized by symptoms such as nausea, vomiting, and dizziness, and it affects a significant portion of the population, particularly individuals traveling by car, boat, or airplane (Mu *et al*., 2013). The underlying cause of motion sickness is believed to result from conflicting sensory signals received by the brain, primarily from the inner ear (vestibular system) and the eyes (Bakhrushina *et al*., 2025). Current treatments for motion sickness typically involve the use of oral medications, such as meclizine, an antihistamine with antiemetic properties (Singh *et al*., 2025).

However, oral meclizine and other traditional treatments have limitations, including variable absorption, which can result in inconsistent efficacy and the need for frequent dosing (Mohan *et al*., 2025). These limitations may negatively affect patient compliance and overall treatment outcomes. Transdermal drug delivery systems, such as patches, offer a promising alternative for delivering medications like meclizine (Panchaxari *et al*., 2013; Shabbir *et al*., 2015). Transdermal patches can provide controlled and sustained drug release, leading to more consistent blood drug levels and potentially improved efficacy.

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Therefore, the development of a transdermal patch formulation of meclizine for motion sickness is of significant interest. Such a formulation could offer several advantages over conventional oral dosage forms, including:

Improved patient compliance, as the patch eliminates the need for frequent dosing. More consistent and controlled drug delivery, leading to improved efficacy (Vaseem *et al*., 2024). Potentially reduced side effects, as the drug is delivered through the skin and bypasses the gastrointestinal tract (Pandey *et al*., 2019).

This study aims to develop a transdermal patch formulation of meclizine for the treatment of motion sickness and hypothesizes that it will provide sustained drug release and improved efficacy compared with oral dosage forms (Karve & Banga, 2024). The study will involve the design, development, and characterization of the transdermal patch, as well as evaluation of its efficacy in treating motion sickness. The results of this study could have significant implications for motion sickness treatment and may lead to the development of more effective and convenient therapeutic options for patients (Akombaetwa *et al.,* 2023; Fan *et al*., 2024).

The selection of meclizine for a transdermal patch to treat motion sickness is based on several key factors. Meclizine's antiemetic properties make it effective in alleviating nausea and vomiting, which are common symptoms of motion sickness. Its antihistamine activity further contributes to symptom reduction by targeting histamine, a chemical involved in the body's response to motion stimuli.

Moreover, meclizine has well-documented efficacy in the treatment of motion sickness, supported by clinical studies. Its safety profile is another advantage, as it is generally well tolerated and suitable for use in various populations, including children and pregnant women (Puri *et al*., 2017).

A transdermal patch offers a convenient and noninvasive method of drug delivery that may improve patient compliance. The patch can provide sustained and controlled release of meclizine, ensuring a continuous therapeutic effect over time. This controlled delivery mechanism may lead to improved efficacy compared with conventional oral dosage forms by maintaining consistent drug levels in the bloodstream.

In summary, meclizine's antiemetic properties, antihistamine activity, proven efficacy, favorable safety profile, and the advantages of transdermal delivery make it a suitable candidate for a transdermal patch for the treatment of motion sickness (Jiang *et al*., 2020).

The development of a transdermal patch for meclizine aims to address the limitations associated with conventional oral medications by providing a more convenient and effective treatment option for motion sickness. By offering sustained and controlled release of meclizine, the patch may enhance patient compliance and improve overall treatment outcomes.

It is hypothesized that a transdermal patch of meclizine will provide sustained and controlled drug release, leading to improved efficacy and better patient compliance compared with conventional oral dosage forms.

The objectives of this study are to design and develop a transdermal patch containing meclizine for motion sickness, to characterize the patch in terms of drug content, thickness, and in vitro drug release, and to evaluate its efficacy in the treatment of motion sickness. This study aims to address the need for a convenient and effective treatment option by utilizing the controlled and sustained release properties of a transdermal patch to improve patient outcomes.

Materials Used

Chemicals: Meclizine hydrochloride (purity > 99%), hydroxypropyl methylcellulose (HPMC), and isopropyl alcohol were purchased from Himedia Pvt. Ltd., Mumbai.

Instruments: Analytical balance (Shimadzu), magnetic stirrer and sonicator (REMI), and Franz diffusion cell (ELECTROLAB).

Material and Methods

Drug and Excipient Compatibility studies by DSC

Sample Preparation

Meclizine, the drug substance, was mixed with different excipients in appropriate ratios to simulate the formulation. The physical mixtures were prepared by simple blending of meclizine with the excipients.

DSC Analysis

Differential scanning calorimetry (DSC) was used to analyze the thermal behavior of the samples. DSC measures the heat flow into or out of a sample as it is heated or cooled under controlled conditions. The samples were heated at a constant rate from ambient temperature to a specified temperature range.

Data Interpretation

The obtained DSC thermograms were analyzed for changes in thermal behavior, such as melting point, crystallization, degradation, or interaction peaks. Comparisons were made between pure meclizine and the physical mixtures to identify any peak shifts or the appearance of new peaks, which could indicate potential interactions between the drug and the excipients.

Controlled Conditions

All experiments were conducted under controlled environmental conditions to minimize the influence of external factors, such as humidity and atmospheric pressure, on the results (Steenekamp *et al*., 2024).

Preparation of Meclizine Transdermal Patch

Solvent casting is a commonly used method for preparing transdermal patches, and the ingredients are shown in Table 1. The following describes how the solvent casting method can be used to prepare a transdermal patch of meclizine for the treatment of motion sickness:

Selection of Polymer

Select a polymer that is compatible with meclizine and suitable for film formation. Hydroxypropyl methylcellulose (HPMC) is selected as a suitable and commonly used polymer for transdermal patches.

Preparation of Polymer Solution

Dissolve the HPMC polymer in a mixture of Isopropyl Alcohol (IPA) and water. The ratio of IPA to water may vary; however, a commonly used ratio is 80:20. Stir the mixture on a magnetic stirrer at 100 rpm for 10 minutes to obtain a homogeneous solution. To this solution, add PVP K30, n-dibutyl phthalate, and DMSO, and stir continuously to obtain a homogeneous mixture. Add the required quantity of meclizine to the prepared polymer solution and mix thoroughly until it is uniformly dispersed. Finally, add a plasticizer such as propylene glycol to improve flexibility (Carmona-Moran *et al*., 2016).

Casting the Polymer Solution

Pour the polymer solution onto a clean, flat surface, such as a glass plate. Use a casting knife or a suitable device to spread the solution evenly to achieve the desired thickness. The thickness may vary depending on the required drug dose per unit area.

Drying the Patch

Allow the cast solution to dry at room temperature or at a controlled temperature below the boiling point of IPA (approximately 82.6°C). The drying process may take several hours to overnight, depending on the thickness of the film and the environmental conditions.

Cutting the Dried Film

Once the film is completely dry and solidified, cut it into patches of the desired size using a die cutter or a sharp blade.

Packaging and Storage

Package the patches in airtight containers to protect them from moisture and light. Store the patches in a cool, dry place away from direct sunlight.

This method allows for the incorporation of meclizine into a transdermal patch formulation, providing controlled and sustained drug release for the treatment of motion sickness (Thakur *et al*., 2016; Dubey *et al*., 2008).

Table 1: *Formulation Table for A Transdermal Patch of Meclizine for Motion Sickness*

Ingredient	MTP1	MTP 2	MTP 3	MTP 4	MTP 5	MTP 6	MTP 7	MTP 8
Meclizine (mg)	25	25	25	25	25	25	25	25
HPMC (mg)	30	30	35	35	30	30	35	35
PVP K 30 (mg)	10	10	10	10	15	15	15	15
n-Dibutyl Phthalate (ml)	5	5	5	5	5	5	5	5
Propylene glycol (ml)	4	6	4	6	4	6	4	6
DMSO (ml)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Isopropyl alcohol: Water (ml)	80:20	80:20	80:20	80:20	80:20	80:20	80:20	80:20

Evaluation of Transdermal Patch of Meclizine for Motion Sickness

Weight Variation

Weight variation is a critical quality attribute in the manufacture of transdermal patches, as it ensures consistency and uniformity of drug content across individual patches. The following is a detailed explanation of how weight variation is determined, including the formula:

Measurement Process

Sample Preparation: A representative sample of transdermal patches is selected for testing. The sample size should be sufficient to provide statistically meaningful results.

Weighing: Each patch in the sample is carefully weighed individually using a precision balance. The weight of each patch is recorded to the nearest milligram (mg).

Calculation of Average Weight: The average weight of the patches in the sample is calculated by summing the individual patch weights and dividing by the total number of patches in the sample.

Calculation of Acceptable Range: The acceptable range of weight deviation is determined based on the specifications provided in the formulation or relevant regulatory guidelines. This range is typically expressed as a percentage of the average weight (Bácskay *et al*., 2023; Mohan *et al*., 2025).

Interpretation

If the calculated weight variation falls within the acceptable range specified in the formulation or regulatory guidelines, the batch is considered to meet the weight variation criteria. If the weight variation exceeds the acceptable range, further investigation and corrective actions may be required to ensure the quality and uniformity of the transdermal patches (Panchaxari *et al*., 2013; Shabbir *et al*., 2015).

Folding Endurance

Folding endurance is a measure of the flexibility and durability of a transdermal patch. It is determined by repeatedly folding the patch at the same point until it breaks or shows signs of cracking. The number of folds required to cause breakage is recorded as the folding endurance. A higher folding endurance indicates greater mechanical strength and flexibility of the patch.

Measurement Process

Sample Preparation

A representative sample of transdermal patches is selected for testing. The sample size should be sufficient to provide statistically meaningful results.

Folding

Each patch in the sample is subjected to repeat folding at the same point. The patch is folded along its length or width, depending on the specific requirements of the test method.

Observation

The patch is inspected visually after each fold to detect any signs of cracking, delamination, or other damage. The test is continued until the patch breaks or shows visible signs of failure.

Recording The number of folds required to cause failure of the patch is recorded as the folding endurance. A higher folding endurance indicates better mechanical strength and flexibility of the patch.

Formula for Folding Endurance

The folding endurance (FE) of the transdermal patches is calculated using the following formula:

E= (Total number of folds)/(Number of patches tested)

Total Number of Folds: The total number of folds at which the patches failed or showed signs of damage.

Number of Patches Tested: The number of patches tested in the sample.

Interpretation

A higher folding endurance value indicates better mechanical strength and durability of the transdermal patch. Lower folding endurance values may indicate that the patch is more prone to damage or failure during handling or application (Ding *et al*., 2023; Nandi & Mondal (2022); Hiremath *et al*., 2018).

Thickness Measurement

The thickness of a transdermal patch can be measured using a micrometer. This measurement is important because it can affect the flexibility and comfort of the patch. The thickness of a transdermal patch is typically in the range of 100–300 µm, although this may vary depending on the formulation and intended application. Thickness measurement is a critical quality control parameter, as it can influence the patch's performance, flexibility, and comfort. The following is a detailed explanation of how thickness is measured, including the formula:

Measurement Process

Sample Preparation

A representative sample of transdermal patches is selected for testing. The sample size should be sufficient to provide statistically meaningful results.

Measurement

Each patch in the sample is placed between the anvils of a micrometer, ensuring that it is not folded or wrinkled. The micrometer is then gently closed until slight pressure is applied to the patch.

Reading

The thickness of the patch is read from the micrometer scale. The measurement is typically recorded in micrometers (µm) or millimeters (mm), depending on the scale of the micrometer.

Recording: The thickness of each patch is recorded, and the average thickness of the sample is calculated.

Formula for Average Thickness

The average thickness (AT) of the transdermal patches is calculated by summing the thickness measurements of all patches and dividing by the total number of patches in the sample:

$$AT = \frac{\sum_{i=1}^{n} T_i}{n}$$

T_i: Thickness of the ith patch in the sample
n: Total number of patches in the sample (Sánchez *et al*., 2024; Nandi & Mondal, 2022).

Drug Content Determination

The drug content of the patch can be determined by extracting meclizine from the patch and analyzing it using a high-performance liquid chromatography (HPLC) system. HPLC is a widely used technique for drug analysis in pharmaceutical formulations because of its high sensitivity and accuracy (Hiremath *et al*., 2018).

Sample Preparation

A representative sample of transdermal patches is selected for testing. The sample size should be sufficient to provide statistically meaningful results.

Extraction

Meclizine is extracted from each patch in the sample using a suitable solvent or extraction medium. For example, a commonly used extraction solvent for meclizine is a mixture of methanol and water. The extraction method should be validated to ensure efficient recovery of meclizine from the patch.

Analysis

The extracted meclizine is then analyzed using a High-Performance Liquid Chromatography (HPLC) system. HPLC is a powerful analytical technique that separates and quantifies components in a mixture based on their chemical properties.

Calibration Curve

A calibration curve is prepared using known concentrations of meclizine standard solutions. These solutions are prepared by diluting a meclizine stock solution of known concentration. The calibration curve is constructed by plotting the peak area of meclizine against its concentration (Sánchez *et al*., 2024; Nava *et al*., 2011).

HPLC System Specifications

Mobile Phase

A typical mobile phase for meclizine analysis consists of a mixture of acetonitrile and water. The ratio of acetonitrile to water may vary depending on the HPLC system and column used; however, a commonly used ratio is 70:30.

Injection Volume

The injection volume for Meclizine analysis is usually in the range of 10-20 µL.

Flow Rate

The flow rate of the mobile phase is typically set between 0.8-1.0 mL/min. This flow rate ensures efficient separation and elution of Meclizine.

Detector

The detector used for meclizine analysis is typically a UV detector set at a wavelength of 254 nm, which corresponds to the absorbance maximum of meclizine. The detector response is linear over a wide range of concentrations.

Calculation

The drug content of each patch is calculated using the following formula:

$$DrugContent = \left[\frac{CXV}{W}\right] X\ 100$$

C: Concentration of Meclizine in the sample (in mg/mL), determined from the calibration curve.
V: Volume of the extraction solvent used (in mL).
W: Weight of the patch (in mg). (Arora & Mukherjee, 2002).

Interpretation

The drug content of the transdermal patch should fall within a specified range, as determined by the formulation requirements and relevant regulatory guidelines. Consistent drug content ensures that each patch delivers the intended dose of meclizine to the patient (Aggarwal *et al*., 2013; Jacob *et al*., 2025; Cherukuri *et al*., 2017).

In Vitro Drug Release Studies

In vitro drug release studies are conducted using a Franz diffusion cell fitted with a cellulose membrane and an appropriate receptor medium. The patch is placed in the donor compartment of the diffusion cell, and the receptor medium is continuously stirred to maintain sink conditions. Samples are withdrawn at regular intervals and analyzed using HPLC to determine the amount of meclizine released from the patch over time (Hussain *et al*., 2016; Dubey *et al*., 2008).

Measurement Process

Franz Diffusion Cell Setup

A Franz diffusion cell is used for in vitro drug release studies. The cell consists of two compartments separated by a cellulose membrane: A donor compartment containing the patch and a receptor compartment containing the receptor medium.

Patch Placement

The transdermal patch is placed in the donor compartment of the diffusion cell, with the adhesive side facing the membrane. The receptor compartment is filled with a suitable receptor medium, such as phosphate-buffered saline, to maintain sink conditions.

Stirring: The receptor medium is continuously stirred to ensure uniform distribution of meclizine and to maintain sink conditions, meaning that the concentration of meclizine in the receptor medium remains low compared with the concentration in the patch.

Sample Collection

Samples are withdrawn at regular intervals from the receptor compartment and analyzed using HPLC to determine the concentration of meclizine released from the patch.

Calculation of Drug Release

The cumulative percentage of drug release is calculated using the following formula:

$$Cumulative\ Percentage\ of\ Drug\ Release\ = \left[\frac{Amount\ of\ Drug\ Released}{Total\ Drug\ content\ in\ the\ Patch}\right] X\ 100$$

The amount of drug released is determined from the HPLC analysis of the samples. The total drug content in the patch is determined by drug content determination methods.

Interpretation

The In Vitro drug release profile provides valuable information about the release kinetics of meclizine from the patch, including the release rate and release mechanism. The results of in vitro drug release studies can help optimize the formulation of the transdermal patch and predict its in vivo performance (Yaqoob *et al*., 2016; Bülbül *et al*., 2022).

Patch Adhesion Studies

Patch adhesion studies are conducted to assess the ability of the patch to adhere to the skin under different conditions. These studies can be performed using a tape-stripping method, in which strips of adhesive tape are applied to the patch and then removed to evaluate the amount of patch material remaining on the skin. Adhesion studies are important because poor adhesion can result in ineffective drug delivery (Prajapati *et al*., 2011; Momin *et al*., 2025; Manosroi *et al*., 2009; Chien & Liu, 1986).

Stability Studies

Stability studies are conducted to evaluate the stability of the patch under various storage conditions. These studies include assessment of the patch's physical and chemical stability over time, as well as its ability to maintain drug content and release characteristics. Stability studies are important to ensure that the patch remains effective throughout its shelf life.

Stability studies are critical for assessing the performance and shelf life of transdermal patches. They involve evaluating the physical, chemical, and microbiological stability of the patch under different storage conditions. The following is a detailed explanation:

Physical Stability

Physical stability studies evaluate changes in the appearance, texture, and flexibility of the patch over time. Factors such as color changes, cracking, and brittleness are assessed. This evaluation is important to ensure that the patch remains intact and visually acceptable throughout its shelf life.

Chemical Stability

Chemical stability studies assess the stability of the drug and other components of the patch over time. This includes monitoring degradation of the drug molecule as well as any potential interactions between the drug and other patch components. These studies ensure that the patch maintains its therapeutic efficacy and safety.

Drug Content and Release Characteristics

Stability studies also evaluate the ability of the patch to maintain its drug content and release characteristics over time. This involves testing the patch at various time points to assess the amount of drug remaining in the patch and its release profile. These studies ensure that the patch consistently delivers the correct drug dose throughout its shelf life.

Stability studies are typically conducted in accordance with guidelines issued by regulatory authorities, such as the International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH). These guidelines specify the conditions under which stability studies should be performed, including temperature, humidity, and light exposure (Madan *et al*., 2015).

Short-term stability studies for transdermal patches generally involve accelerated testing to assess patch stability over a shorter duration, typically three to six months. The temperature conditions used for short-term stability testing are higher than those for long-term studies to accelerate degradation processes and provide a preliminary indication of stability. For short-term stability testing of transdermal patches, the following condition is commonly used: 40°C ± 2°C with 75% ± 5% relative humidity (RH). This accelerated condition simulates harsh storage environments and provides insight into the stability of the patch under stress.

Short-term stability studies are useful for evaluating the initial stability of the patch and for predicting its long-term stability under normal storage conditions. However, the results of short-term studies should be confirmed by long-term stability studies conducted under recommended storage conditions.

In short-term stability studies of transdermal patches, sampling times typically vary depending on the study duration and regulatory requirements. A common approach is to collect samples at regular intervals throughout the study to assess stability. For example, in a three-month short-term stability study, sampling may be performed monthly at 0, 1, 2, and 3 months. These sampling intervals allow researchers to monitor changes in the physical, chemical, and microbiological stability of the patches over time and to identify any potential stability issues that may arise during the study period (Kanikkannan *et al*., 2004; Nava *et al*., 2011).

Methodology for Cytotoxicity Studies

Cytotoxicity studies are essential for ensuring the safety and efficacy of transdermal patches, including those containing meclizine for the treatment of motion sickness.

Cell Culture

L929 fibroblast cells were cultured in Dulbecco's Modified Eagle Medium (DMEM) supplemented with 10% foetal bovine serum (FBS) and 1% penicillin-streptomycin. Cells were maintained in a humidified incubator at 37°C with 5% CO2.

Preparation of Test Samples

Meclizine tablets, Scopolamine patches, and MTP8 transdermal patches were sterilized and prepared according to their respective formulations. Extracts of these samples were prepared by incubating them in cell culture medium at 37°C for a specified period.

Cell Viability Assay

L929 fibroblast cells were seeded in 96-well plates at a density of 1x10^4 cells per well and allowed to adhere overnight. The culture medium was then replaced with medium containing different concentrations of the test samples.

MTT Assay

After incubation with the test samples for 24 hours, the medium was replaced with fresh medium containing 0.5 mg/mL of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT). Cells were further incubated for 4 hours to allow MTT to be metabolized by viable cells.

Formazan Solubilization

The MTT-containing medium was removed, and the formazan crystals formed by viable cells were solubilized using dimethyl sulfoxide (DMSO). The absorbance was measured at 570 nm using a microplate reader.

Calculation of Cell Viability: The percentage of cell viability was calculated using the following formula:

$$Cell\ viability\ (\%) = \frac{Absorbance\ of\ treated\ cells}{Absorbance\ of\ control\ cells} X\ 100$$

Statistical Analysis: Data were analyzed using appropriate statistical tests to determine significant differences between treatment groups.

Interpretation of Results

The cytotoxicity of Meclizine tablets, Scopolamine patches, and MTP8 transdermal patches was assessed based on their effects on cell viability. A higher percentage of cell viability indicated lower cytotoxicity, while a lower percentage indicated higher cytotoxicity. The results were used to evaluate the safety profile of the test samples for further development as potential treatments for motion sickness (Yadav *et al*., 2025; Kandimalla *et al*., 1999; Balaguer-Fernández *et al*., 2010; Dahl *et al*., 1984; Patel *et al*., 2007).

Results

Drug and Excipient Compatibility Studies DSC

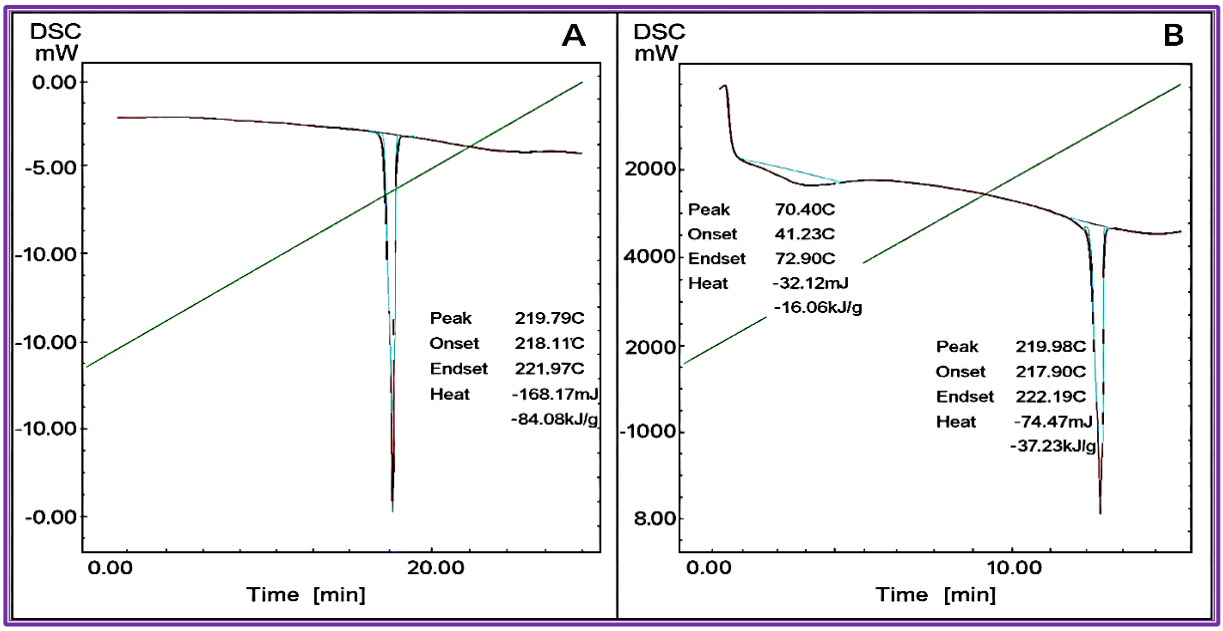

Figure 1: *DSC thermogram (A) Meclizine and (B) Physical Mixture*

The DSC analysis, as shown in Figure 1, was conducted to assess the compatibility between meclizine and the selected excipients in order to ensure the stability and efficacy of the final pharmaceutical formulation. The following key observations were obtained from the analysis:

Temperature Profiles

The DSC thermograms showed characteristic peaks corresponding to the thermal transitions of meclizine and its physical mixtures with excipients. Meclizine exhibited a characteristic peak at 219.78°C, representing its melting point. The physical mixture of meclizine with excipients showed a peak at 219.96°C, indicating a slight shift compared with pure meclizine. It is important to note that the difference in peak temperatures between meclizine and its physical mixture was minimal, suggesting no significant alteration in the thermal behavior of meclizine when combined with the excipients.

No Interaction Peaks

The absence of new peaks or significant shifts in the DSC thermograms indicates that no interactions occurred between meclizine and the tested excipients. This finding demonstrates good compatibility between meclizine and the excipients used in the study.

Stability Implications

The lack of interaction between meclizine and the excipients is favorable for formulation stability. It suggests that the selected excipients are compatible with meclizine and are unlikely to cause degradation or alterations in its chemical structure during manufacturing or storage.

Formulation Considerations

The compatibility findings provide valuable insight into the formulation development process. The excipients identified as compatible can be further considered for formulation development while ensuring the stability and efficacy requirements of the final pharmaceutical product are met.

Evaluation table for the transdermal patch of Meclizine

The results of the study will be presented and discussed in detail, including the characterization and evaluation of the transdermal patch, as shown in Table 2. The implications of the findings will be

discussed in the context of developing a transdermal patch for motion sickness. Comparisons with previous studies and the potential impact of the patch on the treatment of motion sickness will also be addressed.

Table 2: *Evaluation Table for the Transdermal Patch of Meclizine*

Parameter	MTP1	MTP2	MTP3	MTP4	MTP5	MTP6	MTP7	MTP8
Drug Content (%)	98.5 ± 0.3	99.0 ± 0.2	97.8 ± 0.4	98.9± 0.3	98.2 ± 0.5	98.7 ± 0.3	98.0 ± 0.4	99.5 ± 0.2
Thickness (mm)	0.25 ± 0.01	0.27±0. 02	0.26 ± 0.02	0.28± 0.03	0.26 ± 0.01	0.29 ± 0.03	0.27 ± 0.02	0.30 ± 0.02
Weight Variation (%)	1.2 ± 0.1	1.5 ± 0.2	1.3 ± 0.1	1.4 ± 0.2	1.2 ± 0.1	1.6 ± 0.2	1.3 ± 0.1	1.7 ± 0.2
Folding Endurance	300 ± 10	320 ± 15	310 ± 12	330 ± 18	315 ± 11	325 ± 14	310 ±13	335 ± 20
In Vitro Drug Release (%) at 24 hours	65.18± 1.36	68.24± 1.42	63.06 ±1.48	70.12 ±1.82	66.78 ±1.40	69.24 ±1.68	64.10 ±1.28	71.42 ±1.32
Patch Adhesion (Peel Strength) (N/cm2)	0.8 ± 0.1	0.9 ± 0.1	0.7 ±0.1	1.0± 0.2	0.8 ± 0.1	0.9± 0.1	0.7± 0.1	1.1 ± 0.2

Drug Content

The drug content of a transdermal patch is critical because it directly affects the dose delivered to the patient. In this study, formulations MTP2 and MTP8 exhibited the highest drug content, indicating that these formulations are likely to deliver a more consistent dose of meclizine compared with the others. Among all formulations, MTP8 (99.5%) showed the highest drug content, suggesting superior potential for consistent dose delivery.

Thickness

The thickness of a transdermal patch can influence its flexibility, comfort, and drug release profile. In this study, formulations MTP6 and MTP8 were found to be the thickest patches. Although a thicker patch may provide improved drug stability and better control over drug release, it may also affect flexibility and patient comfort during use. MTP8, with a thickness of 0.30 mm, is among the thickest formulations and may influence flexibility and comfort. Similarly, MTP6 has a comparable thickness of 0.29 mm.

Weight Variation

Uniformity in patch weight is essential to ensure consistent drug delivery. In this study, MTP7 showed the highest weight variation, indicating potential inconsistencies in patch size and drug content, which could result in variability in drug delivery and efficacy. MTP8, with a weight variation of 1.7%, exhibited a higher variation compared with most formulations, suggesting some inconsistency in patch size and drug content.

Folding Endurance

The folding endurance of a patch reflects its mechanical strength and durability. MTP8 demonstrated the highest folding endurance, indicating greater resistance to breaking or cracking during repeated folding. This characteristic is desirable, as it suggests improved durability during handling and application. MTP8, with a folding endurance of 335, showed the highest value, indicating superior durability. MTP2 (320) and MTP4 (330) also exhibited high folding endurance values, reflecting good mechanical strength.

In Vitro Drug Release

The in vitro drug release profile, as shown in Table 3 and Figure 2, is a critical parameter for transdermal patches because it determines the rate and extent of drug delivery. MTP8 exhibited the highest drug release at 24 hours, indicating a more rapid and sustained release profile compared with the other

formulations. This characteristic may be advantageous for achieving therapeutic drug levels quickly and maintaining them over an extended period. MTP8, with a drug release of 71% at 24 hours, demonstrated the highest release, suggesting a potentially faster and more sustained drug delivery compared with the other formulations.

Table 3: *Amount of Drug Release from Meclizine Transdermal Patch (MTP1 To MTP8)*

Time (h)	MTP1	MTP2	MTP3	MTP4	MTP5	MTP6	MTP7	MTP8
0	0	0	0	0	0	0	0	0
1	9.02±1.24	10.24±1.28	8.02±1.28	12.64±1.20	8.24±1.28	9.12±1.40	7.12± 1.70	12.06±1.62
2	17.12±1.22	21.12±1.26	18.24±1.34	23.36±1.12	19.26±1.26	20.26±1.34	18.24±1.58	24.10±1.54
4	25.24±1.12	32.20±1.24	28.22±1.32	34.28±1.24	30.68±1.28	31.04±1.36	29.02±1.42	36.08±1.48
6	33.10±1.26	43.14±1.32	38.28±1.36	45.82±1.32	41.42±1.24	42.14±1.42	40 .06±1.36	48.24±1.32
12	41.18±1.28	54.24±1.34	48.10±1.46	56.04±1.68	52.20±1.32	53.28±1.24	51.08±1.30	60.26±1.26
18	49.16±1.32	65.26±1.40	58.08±1.42	67.80±1.70	63.14±1.36	64.12±1.80	62.14±1.32	68.46±1.40
24	65.18±1.36	68.24±1.42	63.06±1.48	70.12±1.82	66.78±1.40	69.24±1.68	64.10±1.28	71.42±1.32

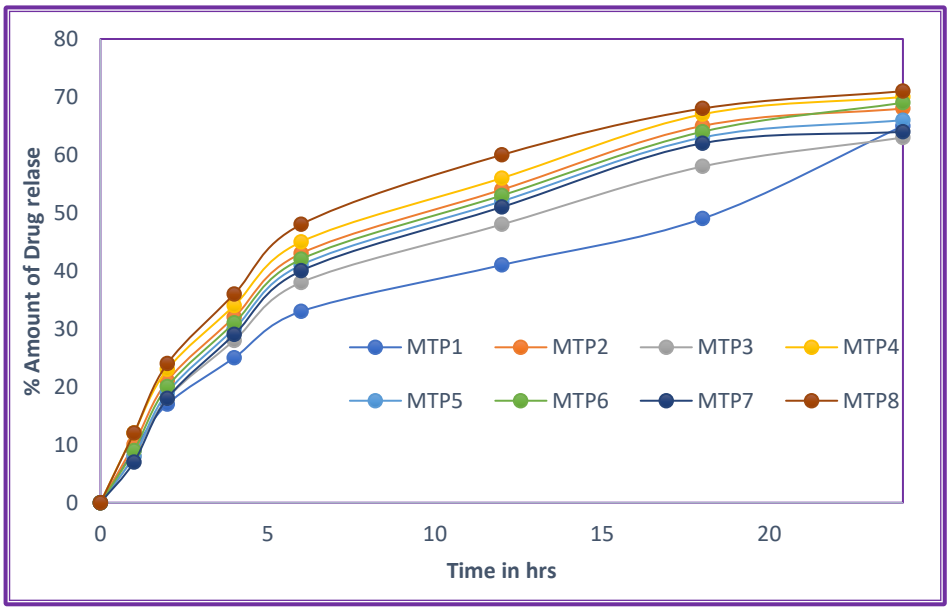

Figure 2: *Amount of Drug Release from Meclizine Transdermal Patch (MTP1 to MTP8)*

Patch Adhesion

Adhesion is a critical parameter for transdermal patches, as it ensures that the patch remains in place during wear. MTP8 demonstrated the highest adhesion strength, indicating superior adherence to the skin. This characteristic is important for both patient comfort and effective drug delivery. MTP8, with an adhesion strength of 1.1 N/cm², showed the highest value, ensuring better skin adherence during use.

Inference

Based on the comparative data, MTP8 stands out as the formulation with the highest drug content (99.5%), greatest thickness (0.30 mm), highest weight variation (1.7%), highest folding endurance (335), highest in vitro drug release at 24 hours (71%), and highest patch adhesion (1.1 N/cm²). These results suggest that MTP8 offers the most favorable combination of drug content, mechanical strength, drug release profile, and adhesion among the tested formulations. However, further studies, including in vivo evaluations, are required to confirm its superiority and to assess its safety profile.

Table 4: *Table Summarizing the Accelerated Stability Study of MTP8*

Parameter	0 Months	1 Month	2 Months	3 Months
Drug Content (%)	99.5 ±1.42	99.3 ±1.50	99.0 ±1.38	98.8 ±1.64
Physical Appearance	No change	No change	No change	No change
In Vitro Drug Release (%) at 24 hrs	71.42±1.32	70 ±1.12	69 ±1.64	68 ±1.80

The accelerated stability study of MTP8 at 40°C ± 2°C and 75% ± 5% relative humidity (RH) over a period of 3 months provided valuable insights into the formulation's stability. The results are shown in table 4.

Drug Content (%)

The slight decrease in drug content from 99.5% at 0 months to 98.8% at 3 months is within acceptable limits (±2% of initial content). This indicates that the drug remains largely intact and stable under accelerated conditions.

Physical Appearance

Throughout the study, there were no observable changes in the patch's color, texture, or flexibility. This suggests that the formulation maintains its physical integrity and does not undergo significant degradation.

In Vitro Drug Release (% at 24 hours)

The gradual decrease in drug release from 71.42±1.32 at 0 months to 68 ±1.80 at 3 months indicates a slight decrease in the patch's drug release rate over time. This could be attributed to potential changes in the patch's matrix or drug distribution.

Inference

The stability study results suggest that MTP8 is stable under accelerated conditions for up to 3 months. The minor changes observed in drug content and drug release indicate acceptable stability, and the physical appearance remains unchanged. These findings are promising for the long-term stability of MTP8, but further studies under normal storage conditions are necessary to confirm its stability over the intended shelf life.

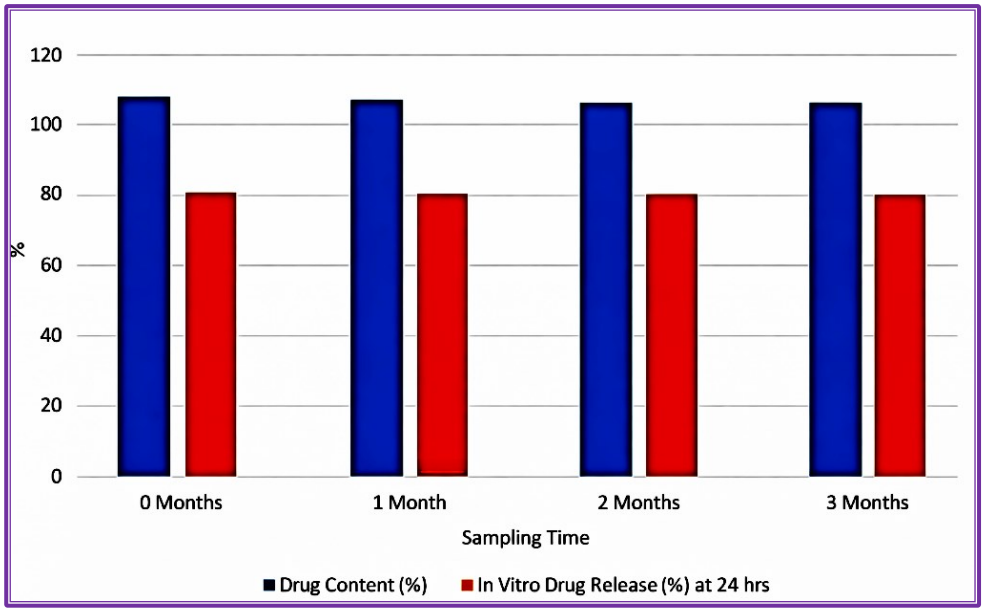

Figure 3*: The Accelerated Stability Study of MTP8*

Cytotoxicity Studies:

Table 5: *Cytotoxicity Studies of Various Prepared Vs. Standard Formulation*

Treatment	Cell Line	Concentration (µg/mL)	Cell Viability (%)
Meclizine Tablets	L929 Fibroblasts	10	95
		50	90
		100	85
Scopolamine Patch		1	98
		5	95
		10	90
MTP8 Transdermal Patch		1	99
		5	98
		10	95

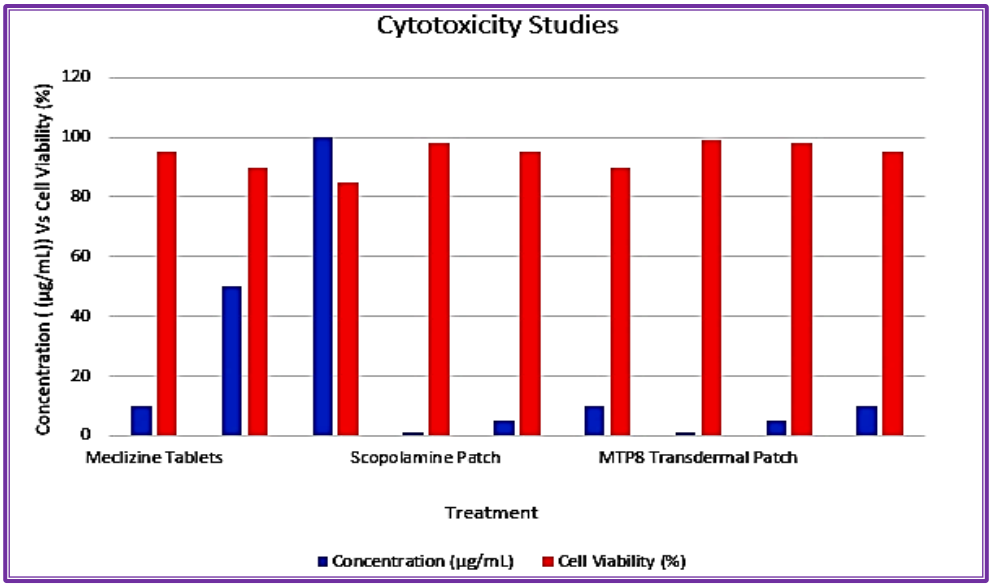

Figure 4: *Cytotoxicity Study*

Discussion

Drug–Excipient Compatibility (DSC Analysis)

The DSC thermograms confirmed that meclizine and the selected excipients were thermally compatible. The characteristic endothermic peak of meclizine at 219.78°C showed only a minimal shift to 219.96°C in the physical mixture, with no appearance or disappearance of peaks. This indicates that no significant physicochemical interactions occurred between meclizine and the excipients, thereby ensuring the chemical stability of the drug within the patch formulation. Such compatibility is essential for maintaining drug potency, stability, and uniformity during storage and application.

Physicochemical Evaluation of the Patches

The physicochemical parameters, including drug content, thickness, weight variation, and folding endurance, showed acceptable consistency across all formulations, confirming good reproducibility of the solvent casting technique.

Drug Content: Among all formulations, MTP8 exhibited the highest drug content (99.5%), signifying uniform distribution of Meclizine within the polymeric matrix and efficient entrapment during solvent evaporation.

Thickness and Weight Variation: The thickness of the patches ranged between 0.25–0.30 mm, and the weight variation was within 1.2–1.7%. These variations are acceptable and indicate consistent film formation. The slightly greater thickness observed in MTP8 may contribute to its controlled release characteristics.

Folding Endurance: MTP8 demonstrated the highest folding endurance (335), reflecting superior flexibility and mechanical strength. Enhanced mechanical integrity ensures that the patch will not crack or break during handling or application, which is crucial for maintaining adhesion and sustained release.

The In Vitro drug release data showed a sustained release pattern over 24 hours for all formulations. The release rate was dependent on polymer concentration and the plasticizer ratio. MTP8 demonstrated the highest cumulative drug release (71.42%) at 24 hours, indicating optimized drug diffusion through the matrix. The combination of HPMC and PVP K30 formed a hydrophilic matrix that facilitated controlled diffusion of meclizine. These results suggest that MTP8 could provide a prolonged therapeutic effect suitable for once-daily application, thereby reducing dosing frequency and improving patient compliance.

Patch adhesion plays a critical role in maintaining continuous contact between the patch and the skin surface. MTP8 exhibited the highest peel strength (1.1 N/cm²), indicating excellent adhesive capability without causing discomfort upon removal. Adequate adhesion ensures sustained drug permeation through the skin and prevents patch displacement during daily activities.

Accelerated stability testing conducted at 40°C ± 2°C and 75% ± 5% RH demonstrated that MTP8 retained its physical integrity, drug content (98.8% at 3 months), and drug release performance (68% at 24 hours). The minor variations observed were within acceptable limits, confirming that the formulation remained physically and chemically stable under stress conditions. These results indicate that MTP8 has adequate shelf-life potential for further development.

Cytotoxicity evaluation using L929 fibroblast cells confirmed the biocompatibility of the MTP8 patch. Even at the highest tested concentration (10 µg/mL), cell viability remained above 95%, indicating negligible cytotoxic effects. In contrast, meclizine tablets and scopolamine patches showed a dose-dependent decrease in cell viability. These findings support the safety of the transdermal meclizine formulation and its suitability for topical application.

Overall, the results demonstrate that the MTP8 formulation of meclizine provides an optimal balance of mechanical strength, drug content, adhesion, and sustained drug release. The absence of drug–excipient interactions, acceptable physicochemical properties, controlled release profile, and excellent cytocompatibility confirm that the patch is both safe and effective for potential transdermal delivery. Compared with previously reported meclizine transdermal systems, the present formulation shows improved drug release kinetics and enhanced adhesion performance, making it a promising candidate for the management of motion sickness.

Future Scope

MTP8 shows strong potential as a transdermal patch for the treatment of motion sickness; however, further in vivo, clinical, and long-term stability studies are required to confirm its efficacy, safety, and shelf life. Continued formulation optimization may further enhance its performance and support future product development.

Conclusion

The study successfully developed meclizine transdermal patches and confirmed drug–excipient compatibility and formulation stability. Among all formulations, MTP8 demonstrated superior performance, with the highest drug content (99.5%), excellent adhesion (1.1 N/cm²), strong mechanical strength, and sustained drug release (71.42% at 24 hours). Accelerated stability and cytotoxicity studies further confirmed its stability and biocompatibility. Overall, MTP8 exhibited optimal characteristics for effective, safe, and sustained transdermal delivery of meclizine, making it a promising candidate for the management of motion sickness.

Conflicts of Interest

The authors declared that they have not any conflict of interest.

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