TRANSDERMAL DELIVERY RATE CONTROL USING AMORPHOUS PHARMACEUTICAL COMPOSITIONS

Field of the Invention

The present invention relates to compositions for the transdermal delivery of physiologically active agents, to uses of those compositions, and to methods for the transdermal delivery of physiologically active agents.

Background of the Invention

There is a constant need for methods for the safe and effective administration of physiologically active agents. For many medications it is important that the administration regime is as simple and non-invasive as possible in order to maintain a high level of compliance by a patient. Oral administration is one administration regime that is commonly used because it is a relatively simple regime to follow. However, the oral administration route is also complicated because of complications associated with gastrointestinal irritation and with drug metabolism in the liver.

Administration of physiologically active agents through the skin ('transdermal drug delivery') has received increased attention because it not only provides a relatively simple dosage regime but it also provides a relatively slow and controlled route for release of a physiologically active agent into the systemic circulation. However, transdermal drug delivery is complicated by the fact that the skin behaves as a natural barrier and therefore transport of agents through the skin is a complex mechanism.

Structurally, the skin consists of two principle parts, a relatively thin outermost layer (the 'epidermis') and a thicker inner region (the 'dermis'). The outermost layer of the epidermis (the 'stratum corneum') consists of flattened dead cells which are filled with keratin. The region between the flattened dead cells of the stratum corneum is filled with lipids which form lamellar phases that are responsible for the natural barrier properties of the skin.

For effective transdermal delivery of a physiologically active agent that is applied to the surface of the skin ('topical application'), the agent must be partitioned firstly from the vehicle into the stratum corneum, it must typically then be diffused within the stratum corneum before being partitioned from the stratum corneum to the viable epidermis, dermis and into the bloodstream.

To overcome some of the problems with transdermal delivery that are associated with transport across the dermal layers ('percutaneous absorption'), physiologically active agents can be formulated with incorporation of one or more drug penetration enhancers. For example, aqueous ethanol can be used as a vehicle in formulations for topical application. Ethanol can act as a penetration enhancer that can increase the flux of an active agent across the skin due to a solvent drag effect (Berner *et al.*, 1989, J. Pharm. Sci, 78(5), 402-406). Padimate O, Octyl salicylate (US Patent no 6,299,900) and Azone™ are further examples of penetration enhancers that have been shown to improve percutaneous absorption.

Compositions that form in-situ have previously found use as biodegradable in situ forming film dressings (US Patent no. 5,792,469) for the formation of barrier surfaces for open dermal wounds.

However to date the use of amorphous compositions for advanced drug delivery systems has been largely restricted to solid-state drug delivery systems such as; oral capsules an example of which is an amorphous paroxetine composition disclosed in WO 99/16440; or drug-in-adhesive, hot-melt type transdermal patches such as those disclosed in US Patent no. 5,662,923, US Patent no. 4,409,206, US Patent no. 6,264,980 and WO 95/18603. These existing amorphous delivery systems suffer from the particular disadvantage of being prone to poor stability during storage over their shelf-life which makes them particularly difficult to design and develop and in many instances has led to variability in drug release and/or dramatic changes in physical appearance (e.g. crystallization and supersaturation in drug-in-adhesive transdermal patch delivery systems). Other workers have also described the use of a transdermal

spray composition that uses a film-forming composition to form a drug reservoir above the skin (US Patent 6,010,716) and such systems are akin to drug-in-adhesive patches that form in-situ.

Consequently there exists a need to develop new amorphous drug delivery systems with improved design and stability whilst building upon the advantages of an amorphous pharmaceutical composition.

Whilst it is feasible that transient formation of an amorphous pharmaceutical composition could occur from existing alcohol-based volatile:non-volatile vehicles such as those disclosed in a dual-phase carrier system that uses benzyl alcohol as the dermal penetration enhancer (US Patent no. 4,820,724), or those acetone-based volatile: non-volatile vehicles using DMSO, DMAC as penetration enhancers (Feldmann, R. J.; Maibach, H. I. Percutaneous penetration of 14C hydrocortisone in man. II. Effect of certain bases and pre-treatments. *Arch. Derm.* 1966, *94*, 649-651). These existing volatile:non-volatile delivery systems suffer from the limitations of using water soluble dermal penetration enhancers that have poor substantivity for the skin and thus are unreliable in maintaining a stable amorphous composition within the skin over the delivery period due to their propensity to wash out of the skin. Further, these prior art systems are prone to irritate the skin due to the solvent nature of the penetration enhancers used within such prior art systems (which results in significant penetration of the enhancer into the viable epidermis).

Other methods of thermodynamic-based enhancement for improving percutaneous absorption have relied upon:

- supersaturation (Coldman, M. F.; Poulsen, B. J.; Higuchi, T. Enhancement of percutaneous absorption by the use of volatile:nonvolatile systems as vehicles. *J. Pharm. Sci.* 1969, *58*, 1098-1102); or
- melting point reduction of the diffusant using deliberate selection of specific enantiomers (US patent no. 5,114,946); or
- melting point reduction using deliberate selection of eutetic mixtures (Touitou E., Chow, D.D., Lawter, J.R. Chiral β-blockers for transdermal

delivery. *Int. J. Pharm.* 1994, *104*, 19-28; Kaplun-Frischoff, Y; Touitou, E. Testosterone skin permeation enhancement by menthol through formation of eutectic with drug and interaction with skin lipids. *J. Pharm. Sci.* 1997, *86*, 1394-1399.; Stott, P.W., Williams, A.C., Barry, B.W. Mechanistic study into the enhanced transdermal permeation of a model β-blocker, propranolol, by fatty acids: a melting point depression effect. Int. J. Pharm. 2001, *219*, 161-176.).

While these methods have all aimed at improvements in percutaneous absorption none have solved the problem of forming a stable amorphous composition capable of controlling the extent and/or profile of transdermal release of a physiologically active agent from within the skin whilst avoiding the skin irritation seen with prior art systems and compositions.

Further the benefits of a stable, in-situ forming amorphous pharmaceutical composition for release rate control within the skin are not foreseen by existing delivery systems which rely upon the control of release rate through the modification of the drug reservoir that resides above the skin such as that described for transdermal matrices that reside above the skin of the host and which are directed at deliberately modifying the profile of the transdermal drug delivery, such examples being described in US Patent no 5,091,186 titled Biphasic transdermal drug delivery device, or US Patent no. 5,613,958, titled Transdermal delivery systems for the modulated administration of drugs or WO 93/00058, titled Solubility parameter based drug delivery system and methods for altering drug saturation concentration.

No admission is made that any reference, including any patent or patent document, cited in this specification constitutes prior art. In particular, it will be understood that, unless otherwise stated, reference to any document herein does not constitute an admission that any of these documents forms part of the common general knowledge in the art in Australia or in any other country. The discussion of the references states what their authors assert, and the applicant reserves the right to challenge the accuracy and pertinency of any of the documents cited herein.

Summary of the Invention

The present invention arises from the inventor's studies of penetration enhancers and in particular from the realisation that, for finite dose formulations, any enhancement in percutaneous absorption of a physiologically active agent is likely to result from one or more of:

(a) an increase in partitioning of the agent from the vehicle containing the agent to the stratum corneum;

(b) an increase in diffusion of the agent within the stratum corneum; and

(c) an increase in partitioning of the agent from the stratum corneum to the viable epidermis.

Previous studies have indicated that the rate and extent of partitioning (a) is already quite efficient with or without added penetration enhancer (Morgan *et al.*, 1998, J. Pharm. Sci, 87(10), 1213-1218). Other studies by the present inventors as well as others have shown that an increase in diffusivity in the stratum corneum (b) is dose dependent for the penetration enhancers studied and therefore once the maximum effect for (b) is achieved no further penetration enhancement is likely to occur.

The present invention arises, at least in part, from the realisation that an increase and/or control in the stratum corneum to viable epidermis partition coefficient (c) may be achieved by deliberately forming an amorphous drug *in situ* so that the drug has increased water solubility within the viable epidermis. To put the invention into practice the present inventor's have found that some combinations of physiologically active agent and penetration enhancer form an amorphous solid *in situ* when they are applied topically and that these combinations can be used for controlling the extent and/or profile of transdermal release of a physiologically active agent.

Accordingly, in a first form the present invention provides a composition including:

- one or more physiologically active agents;

- one or more dermal penetration enhancers; and
- a volatile carrier comprising a pharmaceutically acceptable solvent

wherein the physiologically active agent and the dermal penetration enhancer form an amorphous deposit upon evaporation of the volatile carrier for the purpose of controlling the extent and/or profile of transdermal release of a physiologically active agent.

Amorphous deposits that are formed using compositions of the present invention can be distinguished from solid precipitate (e.g. salt derivative of a drug) or crystalline polymorphs because the amorphous deposit is formed *in-situ* in the skin upon evaporation of the volatile carrier. In this way, the physiologically active agent is able to rapidly partition out of the stratum corneum and into the viable epidermis. In contrast we have found that the formation of crystalline deposits in the skin typically leads to a higher propensity toward skin irritation and a decrease in percutaneous absorption efficiency (due to the need for greater energy to dissolve the crystal prior to diffusional transport). This problem increases in significance for higher melting point crystalline deposits.

Compositions of the present invention may also be more acceptable to consumers than other topical compositions because amorphous deposits have good skin feel and touch when the deposit is rubbed into the skin.

In addition to providing improved percutaneous absorption efficiency, the composition of the invention may also provide lower irritancy than some other delivery systems such as benzyl alcohol sprays, because the relatively low volume and type of volatile and non-volatile excipients used to deliver the active agent results in lower levels of irritation of the skin. Also, the composition of the present invention may avoid problems with crystallisation and/or supersaturation that are encountered with existing amorphous compositions such as amorphous type transdermal patches. This is able to be overcome because in the present invention the amorphous deposit is formed *in-situ.*

Accordingly in a particularly preferred embodiment the invention further provides an aerosol composition for transdermal delivery of a physiologically active agent comprising:

one or more physiologically active agents;

one or more dermal penetration enhancers; and

a volatile carrier comprising a volatile pharmaceutically acceptable solvent wherein topical application of the composition causes the physiologically active agent and dermal penetration enhancer to form an amorphous deposit on evaporation of the volatile carrier for the purpose of controlling the extent and/or profile of transdermal release of a physiologically active agent.

In a further embodiment the invention provides a pharmaceutical composition wherein the carrier comprises a hydrofluorocarbon propellant wherein topical application of the composition as an aerosol provides an amorphous deposit on evaporation of the volatile carrier, wherein the hydrofluorocarbon propellant is HFC-134a.

In a further embodiment the invention provides an aerosol applicator device for transdermal administration of physiologically active agent, the aerosol applicator comprising a chamber for containing an aerosol composition, a valve for delivering the aerosol composition and means for providing a metered dose of spray from the nozzle. The aerosol applicator may further comprise spacing means for spacing the applicator nozzle at a predetermined distance from the skin of the subject on which the spray is to be delivered.

In addition, the use of compositions of the present invention may avoid a disadvantage associated with spray nozzle blockage that is experienced with existing film-forming sprays or aerosols.

In a further aspect the present invention provides a method of delivering an amorphous drug formulation to a host, the method including the steps of applying a topical spray composition containing one or more physiologically active agents, one or more dermal penetration enhancers, and a volatile pharmaceutically acceptable solvent to the skin of the host so that the volatile

solvent evaporates to form an amorphous deposit containing the active agent and the dermal penetration enhancer.

As used herein the term "amorphous" means substantially non-crystalline. It will be appreciated that, unless specified otherwise, the term amorphous includes within its scope a phase that does display some crystallinity. Amorphous for the purpose of the present invention therefore includes a phase in which only part of the deposit is in an amorphous phase. However, provided at least some of the deposit is in the amorphous phase the composition will provide the benefits of the present invention. In practice, it is preferred that at least 10% of the deposit is in the amorphous phase. The methods which may be used to assess the formation of amorphous compositions in potential compositions are Differential Scanning Calorimetry (DCS) and Brightfield microscopy. We have found that these techniques, as described herein in the examples, allow the propensity of composition to form amorphous residues *in-situ* to be readily determined.

The combination of physiologically active agent and dermal penetration enhancer of the present invention is limited functionally to those that together form an amorphous deposit. For this reason it is preferred that both the active agent and the dermal penetration enhancer are non-volatile relative to the volatile solvent so that upon application of the composition to the skin of the host, only the volatile solvent evaporates at physiological temperatures.

In practice, it has been found that the physiologically active agent may be selected from a range of lipophilic physiologically active agents with a molecular weight less than 600 Daltons and a melting point less than 200 degrees Celcius. A list of suitable physiologically active agents includes, but is not limited to: apomorphine, butorphanol, oxybutynin, ropinirole, rivastigmine, buspirone, rizatriptin, tolterodine, zolmitriptan, lacidipine, tropisetron, olanzapine and methyl phenidate or a pharmaceutically acceptable salt or derivative of any one of the aforementioned. Most preferably, the physiologically active agent has a molecular weight less than 400 Daltons and a melting point less than 200 degrees Celcius.

For the same reason, the dermal penetration enhancer may be selected from the classes of enhancers that are lipophilic non-volatile liquids whose vapour pressure is below 10mm Hg at atmospheric pressure and normal skin temperature of 32 degrees Celsius. Preferably, the dermal penetration enhancer has a molecular weight within the range of 200 to 400 Daltons.

The preferred enhancers for use in accordance with the invention may be identified by their balance of organic and inorganic properties. The organic and inorganic values for each penetration enhancer for use in accordance with the invention may be determined by the method described by Fujita in "Production of organic compounds by a Conceptional Diagram" Chem. Pharm. Bull (Tokyo) 2:163 (1954). Whereby area 1 and area 2 possess different physicochemical properties, with area 1 being solvent based enhancers. The preferred penetration enhancers are taken from the area 2 of the conceptional diagram proposed by Hori et al J. Pharm. Pharmacol (1990) 42: 71-72. The preferred area spans an inorganic value of from about 0 to about 200 and an organic value of about 200 to about 400.

The preferred dermal penetration enhancers includes: fatty acids, fatty acid esters, fatty alcohols, glycols and glycol esters, 1,3-dioxolanes and 1,3-dioxanes, macrocyclic ketones containing at least 12 carbon atoms, oxazolidinones and oxazolidinone derivatives, alkyl-2-(N,N-disubstituted amino)-alkanoate esters, (N,N-disubstituted amino)-alkanol alkanoates, and mixtures thereof. Most preferably the dermal penetration enhancer is selected from the list including oleic acid, oleyl alcohol, cyclopentadecanone (CPE-218™), sorbitan monooleate, glycerol monooleate, propylene glycol monolaurate, polyethylene glycol monolaurate, 2-n-nonyl 1,3-dioxolane (SEPA™), dodecyl 2-(N,N-dimethylamino)-propionate (DDAIP) or its salt derivatives, 2-ethylhexyl 2-ethylhexanoate, isopropyl myristate, dimethyl isosorbide, 4-decyloxazolidinon-2-one (SR-38™,TCPI, Inc.), 3-methyl-4-decyloxazolidinon-2-one, and mixtures thereof.

Preferably the volatile solvent has a vapour pressure above 35mm Hg at atmospheric pressure and normal skin temperature of 32 degrees Celsius. In a particularly preferred form of the invention the solvent is ethanol or isopropanol, or a mixture thereof.

The mole ratio of physiologically active agent to dermal penetration enhancer may be between 1:100 and 100:1. More preferably the mole ratio is between 1:20 and 20:1. Most preferably the mole ratio is 1:1.

Conveniently, the composition is a topical spray composition that contains the physiologically active agent, the drug penetration enhancer and the volatile solvent and the method includes the step of spraying the composition onto the skin of the host to form the amorphous deposit containing the physiologically active substance.

In each of the above cases the amorphous deposit is preferably formed in the epidermis of the host, or has a shortened residence time in the viable epidermis or dermis of the host. By 'viable epidermis' is meant the water rich tissue below the stratum corneum.

Brief Description of the Figures

In the accompanying figures:

Figure 1 Graph showing the "Area 2" of the preferred range of inorganic and organic values of enhancers for use in compositions of the invention;

Figure 2 DSC profiles of pure buspirone and buspirone compositions in accordance with the invention containing various penetration enhancers;

Figure 3 Bar chart showing the melting point of a number of buspirone compositions;

Figure 4 Graph showing the cumulative amount of buspirone diffused through human epidermis with time from a control containing buspirone and compositions containing different proportions of buspirone and 2-n-nonyl 1,3-dioxolane penetration enhancer;

Figure 5 Graph showing the cumulative amount of buspirone diffused through human epidermis with time from a control containing buspirone and a compositions containing buspirone and octyl salicylate penetration enhancer;

Figure 6a Graph showing the cumulative amount of buspirone diffused across skin;

Figure 6b Graph showing the plasma concentration of buspirone after transdermal delivery according to the delivery profiles shown in 6a;

Figure 7 Graph showing the cumulative amount of fentanyl diffused through human epidermis with time from a control containing fentanyl and a compositions containing fentanyl and octyl salicylate penetration enhancer;

Figure 8 Graph showing the cumulative amount of fentanyl diffused through human epidermis following application of a transdermal spray composition (95% ethanol) containing fentanyl (5%) and octyl salicylate (5%, OS) penetration enhancer and a further composition containing fentanyl (5%) and cyclopentadecanolide (5%, CPDL) penetration enhancer.

Figure 9 Graph showing the cumulative amount of granisetron diffused through human epidermis with time from a control containing granisetron and a compositions containing granisetron and octyl salicylate penetration enhancer.

Figure 10 Graph showing the cumulative amount of granisetron diffused through human epidermis with time from a control containing granisetron and a composition containing granisetron and padimate O penetration enhancer.

Figure 11 Graph showing the cumulative amount of testosterone delivered with time for compositions of the invention providing a zero order or first order delivery rate using two different dermal penetration enhancers (Padimate O or Octyl salicylate);

Figure 12 Graph showing the plasma concentrations of free testosterone in postmenopausal women at steady state from a transdermal spray composition containing octyl salicylate (ACROSS®) as the dermal penetration enhancer.

Figure 13 Graph showing the plasma concentrations of buspirone in healthy human volunteers at steady state and from a single dose using a transdermal spray composition containing octyl salicylate (ACROSS®) as the dermal penetration enhancer; compared with a single dose of oral buspirone (Buspar) at an oral dose of 15mg in the same subjects (crossover study design).

Detailed Description of the Invention

A benefit of the present invention is that the composition is stable, which means that it is not prone to supersaturation or crystallisation during its pharmaceutical shelf life. This may be contrasted with transdermal patches in which crystallisation of the active agent has presented a problem in the past. Thus the composition of the present invention can be held in a primary container during the shelf life without encountering shelf-life problems of the prior art transdermal patches.

The composition of the present invention may contain from about 0.1% to about 10% of the physiologically active agent, from about 0.1% to about 10% of the

dermal penetration enhancer, and from about 85% to about 99.8% of the volatile solvent by weight.

Preferably, the dermal penetration enhancer is non-irritating to the skin of a recipient. Thus, terpenes, benzyl alcohol and other solvent based enhancers may not be suitable for use in the compositions of the present invention because they irritate the skin by penetrating into the viable regions of the skin in appreciable quantities.

Optionally, the vehicle may have additional pharmaceutical excipients, for example gelling agents, such as carbopol and cellulose derivatives.

The release rate profile of the physiologically active agent from the amorphous deposit into the systemic circulation may be deliberately modified to adjust the delivery profile of the physiologically active agent within the systemic circulation to achieve a desired therapeutic effect.

A zero order release rate profile is achieved by forming an amorphous deposit that has a higher proportion of dermal penetration enhancer relative to the physiologically active agent and/or alternatively selecting a dermal penetration enhancer or combination of dermal penetration enhancers for which the physiologically active agent has a higher saturated solubility. In this way, the leaving tendency of the physiologically active agent from the amorphous deposit is modified and the initial burst of physiologically active agent across the skin is limited. The absolute amount of physiologically active agent can also be increased in the skin reservoir so as to reduce the extent of the plateau in the release rate profile toward the latter half of the dosage interval. The relative amount of crystalline to amorphous deposit may also be modified to achieve the desired release rate profile.

The release rate profile of the physiologically active agent from the amorphous deposit into the systemic circulation preferably approaches zero order in nature so as to reduce the ratio of maximum concentration (C_{max}) to the average concentration (C_{avg}) for the physiologically active agent over the dosage

interval. In this way it is possible to reduce potential side effects associated with elevated C_{max} to C_{avg} ratios. For example C_{max} to C_{avg} ratios less than 2 and more preferably less than 1.5.

Conversely a first order release rate profile can be achieved by selecting a dermal penetration enhancer or combination of dermal penetration enhancers in which the physiologically active agent has a lower saturated solubility thus increasing the leaving tendency of the physiologically active agent from the amorphous deposit, and increasing the initial burst of physiologically active agent across the skin. The absolute amount of physiologically active agent per unit area can also be reduced in the skin reservoir so as to increase the extent of the plateau in the release rate profile toward the latter half of the dosage interval. The relative amount of crystalline to amorphous deposit may also be modified to achieve the desired release rate profile.

Preferably, the release rate profile of the physiologically active agent from the amorphous deposit into the systemic circulation is substantially first order in nature so as to increase the ratio of C_{max} to C_{avg} and decrease the time for maximum systemic concentration (t_{max}) for the physiologically active agent over the dosage interval. In this way it is possible to decrease the time to onset of therapeutic response or increase the therapeutic response after a single dose interval. For example C_{max} to C_{avg} ratios greater than 1.5 and more preferably greater than 2 and t_{max} less than 4 to 6 hours and more preferably less than 2 to 3 hours.

The invention will now be described with reference to the following examples. It is to be understood that the examples are provided by way of illustration of the invention and that they are in no way limiting to the scope of the invention.

Examples

The method of in vitro diffusion of various physiologically active agents across human skin was used in accordance with the invention to assess the effect of addition of the various dermal penetration enhancers on transdermal drug delivery.

The methods of Differential Scanning Calorimetry (DSC) and Brightfield Microscopy were used in accordance with the invention to assess whether or not a composition is amorphous after evaporation of the volatile liquid and where necessary the extent of amorphous material present.

Diffusion Studies

In vitro diffusion experiments were performed using stainless steel flow-through diffusion cells, using human epidermis maintained at 32°C. The receptor solution consisted of either 10% Ethanol in 0.002% Sodium Azide. The non-occlusive composition was added to each of four cells at a finite dose of 5μl per cell. Samples were collected at appropriate time points and analysed by reverse-phase high performance liquid chromatography (RP-HPLC).

Table 1. HPLC conditions for receptor solution analysis.

Parameters	Method		
	Buspirone	Granisetron	Fentanyl
Column	Symmetry C18 (3.9*150mm) 5μm	Symmetry C18 (3.9*150mm) 5μm	Symmetry C18 (3.9*150mm) 5μm
Mobile Phase	Line A: 20% AcN in 0.01M KH2PO4 @ pH 2.85nM Line B: 90 % AcN @ pH 2.8	25% Acetonitrile in water with 0.14% triethylamine and 0.06% glacial acetic acid	Line A: 5nM TEA (milli-Q), pH 10.9 Line B: 100% AcN
Pump	Isocratic: 70% A 30% B	Isocratic	Gradient: Time %A %B 80 20 8.5 63 37 9 80 20 11 80 20
Flow rate	1.0 ml/min	1.0 ml/min	1.0 ml/min
Absorbance	239 nm	300 nm	210 nm
Injection volume	50 μl	50 μl	50 μl
Column Temp.	40 °C	-	-

Differential Scanning Calorimetry (DSC)

DSC is used to determine changes in physicochemical properties of compounds in combination with a dermal penetration enhancer after volatile liquid evaporation. This enables determination of the optimum ratio of drug to enhancer, which results in an altered amorphous form to enhance percutaneous absorption (i.e. enhance transdermal drug delivery).

The amorphous nature of a mixture of compounds is evident in a depressed melting point of the mixture of compounds relative to the melting point of any of the individual components of the mixture. In addition, a decrease in peak height and heat of enthalpy along with a broadening of the melting transition temperature are also characteristics inherent of amorphous compounds.

Firstly, mole ratio mixtures of the physiologically active agent and dermal penetration enhancer shown were prepared in 95% ethanol as per the compositions shown. A 10μl aluminium micro DSC pan was placed in a 50μl DSC aluminium pan, and 5μl aliquots of each formulation were pipetted into the 10μl DSC pan. The volatile liquid (95% ethanol) was allowed to evaporate and

further aliquots were re-applied until a sufficient quantified residue of physiologically active agent and dermal penetration enhancer remained.

The pans were maintained at ambient temperature and 33% relative humidity for 24 hours (which simulated a typical in-use daily dosage interval), after which the pans were covered and hermetically sealed. DSC was then performed under a stream of nitrogen, at 10ºC per minute, within the temperature range that was drug dependent.

Brightfield Microscopy

Brightfield microscopy was used to determine the crystallisation/amorphous solid potential of various physiologically active agents in combination with a dermal penetration enhancer after volatile liquid (95% ethanol) evaporation. This enables a determination of the optimum ratio of drug to enhancer in conjunction with DSC.

5μl aliquots of each formulation were pipetted onto a clean, glass slide at 32ºC/ambient relative humidity. After evaporation of the volatile liquid vehicle (95% v/v ethanol), the slide was viewed under a Leica Wild microscope, linked to SPOT diagnostics camera, at 1 and 24 hours. The nature of the mixture remaining after 24 hours is assessed and the proportion by volume of amorphous material may be visually estimated.

Example 1

Figure 1 shows the organic and inorganic values for typical penetration enhancers that can be used in accordance with the invention (determined by the method described by Fujita in "Production of organic compounds by a Conceptional Diagram" Chem. Pharm. Bull, Tokyo **1954** 2:163). Area 1 being solvent based dermal penetration enhancers which are prone to irritate the skin or evaporate off it when using non-occlusive percutaneous or transdermal drug delivery systems. The preferred penetration enhancers are taken from the area 2 of the conceptional diagram (as originally proposed by Hori et al J. Pharm. Pharmacol **1990** 42: 71-72). The preferred area spans an inorganic value of from about 0 to about 200 and an organic value of about 200 to about 400.

Example 2

This example examines compositions of the invention formed by the combination of buspirone with a range of penetration enhancers having a range of organic and inorganic characteristics.

The physicochemical properties of buspirone are shown in the following table:

	M.Wt (Da)	LogP	M.Pt (°C)
Buspirone	385.51	2.63	103.5

The penetration enhancers examined in this example were 2-n-nonyl, 1,3-dioxolane (SEPA), dodecyl 2-(N,N-dimethylamino)-propionate (DDAIP) and cylclopentadecanone (CPL).

Referring to Figure 1 there is shown a plot of inorganic index against organic index for potential penetration enhancers. The organic and inorganic values are determined according to the procedure of Fujita A Chem. Pharm. Bull (Tokyo) 2:173 (1954). The compounds 2-n-nonyl, 1,3-dioxolane, dodecyl 2-(N,N-dimethylamino)-propionate (DDAIP) and cylclopentadecanone demonstrate a range of organic, inorganic index in Area 2 generally defining organic index between 0 and 200 and an organic index between 200 and 400.

All formulations were prepared by accurately weighing the appropriate amount of physiological active and penetration enhancer into a volumetric flask and made up to volume with ethanol (95% v/v).

Control formulations:

Buspirone base; and

Test Formulations

All enhancer containing (test) formulations were prepared as 1:1 and 4:1 mole ratios of drug:enhancer unless stated.

Buspirone: Isopropyl myristate (IPM)

Buspirone: Dodecyl 2-(N,N-dimethylamino)-propionate (DDAIP)

Buspirone: 2-n-nonyl, 1,3-dioxolane (SEPA)

Buspirone: Laurocapram (Azone™, AZ)

Buspirone: Myristic Acid (MA)

Buspirone: 2-Ethyl Acetate (EA)

2-Ethyl Acetate (EA) which has a molecular weight of 88.1Da and boiling point of 77.1°C is included as an example of a solvent based dermal penetration enhancer which is not preferred for use in this invention because it is prone to irritate the skin or evaporate off it when using non-occlusive percutaneous or transdermal drug delivery systems.

DSC profiles were determined for the control and test formulations pure buspirone and buspirone with several particular enhancers with a mole ratio of 1:1. Solvent evaporation, for each formulation, resulted in a melting point reduction. Figure 2 demonstrates characteristics inherent of amorphous compounds, for example the decrease in melting point, ΔH and peak height, and the broadening of the melting transition temperature. DSC analysis of buspirone with each enhancer, at mole ratio of 1:1 and 4:1, showed a reduction in melting point, with buspirone:azone 1:1 ratio remaining as an oil thus presenting no melting point (Figure 3).

Figure 3 also shows the inability of the solvent based enhancer (2-ethyl acetate) to reliably reduce the melting point of buspirone. This disadvantage combined with its propensity to irritate the skin is why solvent based enhancers are not preferred for the non-occlusive transdermal delivery system of this invention.

Microscopy of each binary mixture confirmed the part-amorphous state of buspirone. In most cases an unevenly spread oily film was observed, with occasional few small crystals present or some compositions with some needle shaped crystals protruding.

Diffusion experiments (Table 2) were performed on various 95% ethanol formulations containing buspirone and 2-n-nonyl, 1,3-dioxolane;

Buspirone diffusion through human skin (epidermis) confirms an increase in buspirone permeability at the 1:1 mole ratio with 2-n-nonyl, 1,3-dioxolane of 2.6. However, the 4:1 ratio demonstrated no significant enhancement (Table 2, Figure 4).

Table 2. Summary of Mean Cumulative Amount penetrated across human epidermis at 24 hours (Q_{24h}) ($\mu g/cm^2$) for various formulations.

Formulation (all formulations in 95% v/v Ethanol)	n	Mean Q_{24h} Buspirone ($\mu g/cm^2$) ±SEM
3.85% Buspirone in 95% EtOH	8	1.028±0.307
3.85% Buspirone : 2.003% 2-n-nonyl, 1,3-dioxolane (1:1 mol ratio)	4	2.621±0.675
3.08% Buspirone : 0.4006% 2-n-nonyl, 1,3-dioxolane (4:1 mol ratio)	4	0.904±0.188

Example 3

Figure 5 shows the cumulative amount of buspirone diffused across human epidermis with time from a control containing buspirone in volatile liquid (95% ethanol) and a composition containing buspirone and octyl salicylate penetration enhancer in the same volatile liquid. Addition of the octyl salicylate to the transdermal spray formulation caused a significant marked increase in the amount of buspirone diffusing across the skin over 24 hours ($p<0.05$).

Example 4

The amorphous deposit formed *in situ* by the compositions of Examples 2 and 3 result in an enhanced delivery of buspirone across the skin. The delivery profile across the skin for these enhanced amorphous compositions can be either a zero order delivery profile or a first order delivery profile, whichever of these situations is desired for the particular pharmacological therapy. The composition without the enhancer shows poor penetration enhancement of buspirone across the skin and consequent low amounts of drug penetrating across the skin. Figure 6a depicts the diffusion profile that may be obtained by transdermal zero and first order administration of buspirone in accordance with the invention and figure 6b shows the approximated plasma concentration profile that would correspond to each delivery rate profile shown in figure 6a. The diffusion profiles of amorphous deposits investigated confirm an increase in the delivery

of the active across the skin. The rate of delivery may be modified to suit the desired pharmacological therapy by either changing the dermal penetration enhancer used in the composition or by changing the ratio of drug to enhancer in the composition.

Example 5

Figures 7 and 8 demonstrate the ability to modify the fentanyl delivery rate by changing penetration enhancer. Therefore, the leaving tendency may be modified to suit the desired delivery rate. A stable zero order delivery rate in the case of fentanyl would be desirable for the treatment of chronic pain.

Example 6

Figure 9 and 10 demonstrates the ability the ability to modify the granisetron delivery rate by changing penetration enhancer and/or the ratio of drug to enhancer in the composition.

Example 7

The drug to enhancer ratio was varied to modulate the delivery rate of testosterone *in vitro* using transdermal spray vehicles. Varying concentrations of testosterone (Tes) and the dermal penetration enhancers octyl salicylate (Osal) or padimate O (PadO) were applied to shed snake skin *in vitro* from a finite vehicle volume (5 $\mu l/cm^2$) designed to mimic *in vivo* dosing. The rate and extent of drug permeation was modelled to a single compartment model with a first-order rate constant (Kubota, K. *J. Pharm. Sci.* **1991**, *80*, 502-504). The *in vitro* diffusion model allowed accurate and rapid characterisation of the diffusion profiles using three parameters alone, total % absorbed (*A*, units μg), rate constant (α, units h^{-1}) and lagtime (*l*, units h). Varying Tes to Osal ratio changed *A* and *l* significantly ($p < .001$) and increased Tes loading in a PadO formulation resulted in zero-order delivery *in vitro* over 48 h as shown in Figure 11 (suggesting the drug solubility in the enhancer plays a role in drug release). For practical formulation development purposes a simple compartmental diffusion model can be used to optimise the drug to enhancer ratio in order to modulate drug permeation across the skin.

Example 8

The plasma concentrations of free testosterone were determined in postmenopausal women at steady state from a transdermal spray composition containing testosterone 5% w/v and octyl salicylate 8% w/v in 95% ethanol. A zero-order delivery profile was obtained and is shown in Figure 12.

Example 9

Figure 13 shows the results for a pharmacokinetic study in 6 normal healthy male volunteers which studied a single transdermal spray dose followed by washout period; then a single oral dose of buspirone 15mg (3 x 5mg tablets; BuSpar) was given followed by washout period after which the volunteers received multiple transdermal doses once daily until steady state was achieved. The daily transdermal dosage applied was 4 x 91μl sprays of the buspirone metered-dose transdermal spray (MDTS®) containing 4% w/v buspirone and 5% w/v octyl salicylate applied to the forearm.

For a single dose of the oral buspirone tablet (15mg) the mean half-life was 2 hours and mean tmax was 0.9 hours. The mean Cavg was 0.15 ng/ml and mean Cmax was 1.3ng/mL, with the calculated ratio of Cmax to Cavg having a value of 8.7. In contrast, following once-daily dosing of the buspirone transdermal spray of the invention the mean Cavg was 0.32 ng/ml and mean Cmax was 0.49ng/mL, with the calculated ratio of Cmax to Cavg having a value of 1.5 and a mean tmax of 9.3 hours. The buspirone composition of this example could be expected to have particular advantages for the use in humans or animals for the treatment of general anxiety disorders and attention deficit hyperactivity disorder whereupon the stable zero order transdermal delivery of the drug and avoidance of a high Cmax concentration provided by the invention would beneficially result in a reduction in side effects such as gastrointestinal disturbances, drowsiness, impaired driving or motor ability and/or impaired cognitive function.

CLAIMS

1. A pharmaceutical composition for transdermal delivery comprising
   - one or more physiologically active agents;
   - one or more dermal penetration enhancers; and
   - a volatile pharmaceutically acceptable carrier comprising a volatile solvent;

and wherein the physiologically active agent and dermal penetration enhancer form an amorphous deposit upon evaporation of the volatile carrier, said amorphous deposit forming a reservoir within the stratum corneum; and wherein the composition has a release rate profile of physiologically active agent so as to provide a ratio of the maximum concentration (C_{max}) to the average concentration (C_{avg}) for the physiologically active agent over the dosage interval within the range of 1 to 5.

2. A pharmaceutical composition according to claim 1 wherein the composition provides a substantially zero order or substantially first order release rate profile of the physiologically active agent over the dosage interval whichever is desirable for the therapeutic effect of the physiologically active agent.

3. The transdermal drug delivery system according to claim 1, wherein the composition provides a zero order release rate profile of the physiologically active agent so as to reduce the ratio of the maximum concentration (C_{max}) to the average concentration (C_{avg}) to a value less than 2 for the physiologically active agent over the dosage interval in order to reduce potential side effects associated with elevated C_{max} to C_{avg} ratios.

4. The transdermal drug delivery system according to claim 1, wherein the composition provides a zero order release rate profile of the physiologically active agent so as to reduce the ratio of the maximum concentration (C_{max}) to the average concentration (C_{avg}) to a value less than 1.5 for the physiologically active agent over the dosage interval in order to reduce potential side effects associated with elevated C_{max} to C_{avg} ratios.

5. The transdermal drug delivery system according to claim 1, wherein the composition provides a first order release rate profile of the physiologically active agent so as to increase the ratio of C_{max} to C_{avg} to a value greater than 1.5 and decrease the time for maximum systemic concentration (t_{max}) to less than 6 hours for the physiologically active agent over the dosage interval in order to decrease the time to onset of therapeutic response or increase the therapeutic response after a single dose interval.

6. The transdermal drug delivery system according to claim 1, wherein the composition provides a first order release rate profile of the physiologically active agent so as to increase the ratio of C_{max} to C_{avg} to a value greater than 2 and decrease the time for maximum systemic concentration (t_{max}) to less than 3 hours for the physiologically active agent over the dosage interval in order to decrease the time to onset of therapeutic response or increase the therapeutic response after a single dose interval.

7. The transdermal drug delivery system according to claim 1, wherein the physiologically active agent is a steroid, hormone derivative, opioid analgesic, thrombolytic, antinauseant, anxiolytic, anti-migraine compound, antihypertensive agent, anti-malarial compound, bronchodilator, anti-depressant, anti-Alzheimer's agent, neuroleptic and antipsychotic agent, anti-Parkinson's agent, anticholinergic, antiandrogen or anoretic agent.

8. The transdermal drug delivery system according to claim 1, wherein the physiologically active agent is testosterone, oestradiol, ethinyloestradiol, nestorone, levonorgestrel, lacidipine, norethisterone acetate, buspirone, fentanyl, buprenorphine, ropinirole, scopolamine, granisetron, amlodipine, oxybutynin, rivastigmine, rizatriptan, primaquine, fluoxetine, paroxetine, tacrine, N-0923 and mazindol.

9. A pharmaceutical composition according to claim 1 wherein the carrier comprises a hydrofluorocarbon propellant wherein topical application of the composition as an aerosol provides an amorphous deposit on evaporation of the volatile carrier.

10. A pharmaceutical composition according to claim 9 wherein the hydrofluorocarbon propellant is HFC-134a.

11. A pharmaceutical composition according to claim 9 wherein the volatile solvent and propellant provide a single phase solution of the active agent,

12. A pharmaceutical composition according to claim 1 wherein the composition comprises from 0.1% to 10% of physiologically active agent; from 0.1 to 10% by weight of dermal penetration enhancer and from 85% to 99.8% by weight of volatile carrier.

13. A pharmaceutical composition according to claim 9 wherein the hydrofluorocarbon propellant is from 15 to 50% by volume of the total pharmaceutical composition.

14. A pharmaceutical composition according to claim 1 wherein the physiologically active agent component comprise a molecular weight of less than 600 Daltons and a melting point less than 200°C.

15. A pharmaceutical composition according to claim 1 wherein the penetration enhancer has an organic nature value of from 200 to 400 and an inorganic nature value of from 0 to 200.

16. A pharmaceutical composition according to claim 1 wherein the penetration enhancer is a lipophilic liquid having a vapour pressure below 10mmHg at atmospheric pressure and a temperature of 32°C and a molecular weight in the range of from 200 to 400 Daltons.

17. A pharmaceutical composition according to claim 1 wherein the penetration enhancer comprises one or more compounds selected from the groups consisting of fatty acids, fatty acid esters, fatty alcohols, glycols and glycol esters, 1,3-dioxolanes and 1,3-dioxanes, macrocyclic ketones containing at least 12 carbon atoms, oxazolidinones and oxazolidinone derivatives, alkyl-2-(N,N-disubstituted amino)-alkanoate esters, (N,N-disubstituted amino)-alkanol alkanoates, and mixtures thereof, most preferably the dermal penetration enhancer is selected from the list including oleic acid, oleyl alcohol, cyclopentadecanone, sorbitan monooleate, glycerol monooleate, propyle glycol monolaurate, polyethylene glycol monolaurate, 2-n-nonyl 1,3-dioxolane, dodecyl

2-(N,N-dimethylamino)-propionate or its salt derivatives, 2-ethylhexyl 2-ethylhexanoate, isopropyl myristate, dimethyl isosorbide, 4-decyloxazolidinon-2-one, 3-methyl-4-decyloxazolidinon-2-one, and mixtures thereof.

18. A pharmaceutical composition according to claim 1 wherein the solvent comprises ethanol, isopropanol or a mixture thereof.

19. A pharmaceutical composition according to claim 1 wherein the molar ratio of the physiologically active agent compound and the dermal penetration enhancer is from 1:20 to 20:1.

20. A pharmaceutical composition according to claim 1 wherein the composition is contained in a chamber of a spray applicator device comprising a valve for delivering the composition from the chamber, a nozzle for dispersing the composition as an aerosol and means for providing a metered dose of aerosol from the nozzle.

21. Use of a physiologically active substance in preparing a spray composition for enhanced percutaneous absorption by applying a spray of a pharmaceutical composition according to claim 1 to the skin of a subject to form an amorphous deposit of the active agent and penetrating enhancer upon evaporation of the volatile solvent whereby partitioning of the physiologically active agent from the stratum corneum to the viable epidermis is enhanced.

22. Use of a physiologically active agent for preparation of a spray composition for providing substantially zero order release rate profile of the physiologically active agent by applying a spray of the composition according to claim 1 to the skin of a subject wherein the potential side effects associated with elevated maximum bloodstream concentrations of the active (C_{max}) over the dosage interval are reduced, whilst still maintaining effective average bloodstream concentrations of the active (C_{avg}).

23. Use of a physiologically active agent in preparation of a spray composition for substantially first order release rate profile of the physiologically active agent by applying a spray of a pharmaceutical composition according to claim 1 to the skin of a subject wherein the time to onset of a therapeutic response to the active or an increase in the therapeutic response to the active is

achieved by a decrease in the time to maximum concentration of the active in the bloodstream (t_{max}) and by an increase in the ratio of C_{max} to C_{avg} over the dosage interval.