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Liquid Crystal Nanodispersions Enable the Cutaneous Delivery of Photosensitizer for Topical PDT: Fluorescence Microscopy Study of Skin Penetration

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Abstract: Topical photodynamic therapy (PDT) has been applied to almost all types of nonmelanoma skin cancer and numerous superficial benign skin disorders. Strategies to improve the accumulation of photosensitizer in the skin have been studied in recent years. Although the hydrophilic phthalocyanine zinc compound, zinc phthalocyanine tetrasulfonate ($ZnPcSO_4$) has shown high photodynamic efficiency and reduced phototoxic side effects in the treatment of brain tumors and eye conditions, its use in topical skin treatment is currently limited by its poor skin penetration. In this study, nanodispersions of monoolein (MO)-based liquid crystalline phases were studied for their ability to increase $ZnPcSO_4$ uptake by the skin. Lamellar, hexagonal and cubic crystalline phases were prepared and identified by polarizing light microscopy, and the nanodispersions were analyzed by dynamic light scattering. *In vitro* skin penetration studies were performed using a Franz's cell apparatus, and the skin uptake was evaluated *in vivo* in hairless mice. Aqueous dispersions of cubic and hexagonal phases showed particles of nanometer size, approximately 224 ±10 nm and 188 ± 10 nm, respectively. *In vitro* skin retention experiments revealed higher fluorescence from the $ZnPcSO_4$ in deeper skin layers when this photosensitizer was loaded in the hexagonal nanodispersion system when compared to both the cubic phase nanoparticles and the bulk crystalline phases (lamellar, cubic and hexagonal). The hexagonal nanodispersion showed a similar penetration behavior in animal tests. These results are important findings, suggesting the development of MO liquid crystal nanodispersions as potential delivery systems to enhance the efficacy of topical PDT.

Keywords: Liquid crystalline phases, nanodispersion, skin cancer, skin penetration, photodynamic therapy, zinc phthalocyanine.

1. INTRODUCTION

Topical photodynamic therapy (PDT) has been applied to almost every type of superficial nonmelanoma skin cancer and numerous benign skin disorders [1-2]. PDT is based on the administration of a photosensitizing drug and its selective retention in malignant tissue and its subsequent activation by light at specific wavelengths, causing cell death by the production of free radicals and/or reactive oxygen species [3, 4]. Numerous strategies have been studied in recent years in attempts to improve the accumulation of photosensitizers and their precursors in the skin, including the use of microemulsions [5], micelles [6], liposomes [7], ceramic-based nanoparticles [8], gold nanoparticles [9], polymer nanoparticles [10], dendrimers [11], invasomes [12] and liquid crystalline phases [13-15]. Lipophilic phthalocyanines (e.g., zinc and chloroaluminum compounds) have been widely used as photosensitizers in preclinical studies of PDT for the treatment of skin cancer [16, 17]. In contrast, the water-soluble zinc phthalocyanine tetrasulfonate ($ZnPcSO_4$) has displayed high photodynamic efficiency and reduced phototoxic side effects in the treatment of brain and ocular tumors [18]. However, with exception of a few studies [19-21], there is a lack of data on the application of $ZnPcSO_4$ in PDT for skin cancer.

Their ability to control the release of drugs and their excellent biocompatibility make liquid crystals based on polar lipids such as monoolein (MO) particularly attractive as delivery matrices for the topical and transdermal delivery of drugs [20, 22-25], including prodrugs and photosensitizers in PDT for skin cancer [13, 14]. Moreover, liquid crystalline lipid-water phases with an inverse structure (reverse hexagonal and the cubic phases) can co-exist in equilibrium with an excess of water, forming kinetically stable colloidal dispersions [26].

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$ZnPcSO_4$ (MW 898.15 g/mol) presents four charged groups in its molecular structure, which makes the molecule hydrophilic and prevents its penetration into the lipophilic stratum corneum, the main skin barrier. The low passive penetration of the drug, therefore, motivates the use of nanoparticles to improve drug entry into deeper skin layers. Nanoparticles of cubic and hexagonal lipid-water phases have been used for the development of controlled-release formulations of biologically active agents in the field of drug delivery and have demonstrated their potential as a new topical delivery system [15]. In this context, we studied several bulk MO-based liquid crystalline phases and their nanodispersions *in vitro* and *in vivo* with respect to their ability to increase the skin uptake of $ZnPcSO_4$, a crucial condition for the effectiveness of topical PDT for skin cancer.

2. EXPERIMENTAL PROCEDURE

2.1. Materials

A commercial grade of monoolein (MO) (Myverol 18:99) was purchased from Danisco Ingredients (Copenhagen, Denmark) and used as received. Oleic acid (OA) was obtained from Sigma (St. Louis, MO, USA). Polysorbate 80 and citrate buffer were provided by BDH Chemical, Ltd. (Poole, UK). Zinc phthalocyanine tetrasulfonate ($ZnPcSO_4$) was purchased from Frontier Scientific Inc., (Logan, UT). Milli-Q water was obtained by a Millipore system (Millipore Corporation). Sephadex LH20 was provided by GE Healthcare, methanol was acquired from Bdick & Jackson (B & J ACS / HPLC Certified Solvent) and poloxamer 407 was purchased from BASF (São Paulo, Brazil).

2.2. Preparations of Bulk Gels of Lyotropic Liquid Crystalline Phases and Polarized Light Microscopy Characterization

The bulk gels of lyotropic liquid crystalline phases were development based on experiences of the research group in field of liquid crystalline phases technology [13, 15, 34]. The lamellar and cubic phase gels was prepared by first melting MO at 42ºC followed by the addition of water at 10% and 30% (w/w), respectively. The hexagonal phase was prepared adding OA in the proportion

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MO:OA:water of 77:5:18 (w/w/w). The preparations were loaded with 0.5 mg of $ZnPcSO_4$/3g formulation after solubilization in the aqueous phase. All preparations were kept at room temperature and protected from the light for 24 h. The formulations were examined through a polarized light microscope (Axioplan 2 Image Pol microscope, Carl Zeiss, Oberkochen, Germany) to characterize their liquid crystalline structure.

2.3. Nanodispersion Obtainment and Characterization

The cubic and hexagonal phase gels, obtained as described above, were dispersed by vortex-mixing in a pH 6.0 citrate buffer containing 1% or 1.5% of poloxamer in the proportion 10:90 (gel:buffer), respectively. The dispersions were loaded with $ZnPcSO_4$ at the same concentration used for the bulk gels. The resulting dispersions were sonicated in an ice bath for 2 min, centrifuged at 1,901 × *g* for 10 min and then filtered through a 0.8 μm membrane [21]. The mean diameter and particle size distribution of each dispersion were determined using a dynamic light scattering system (Zetasizer, NanoZS, Malvern, UK) at 90º with a He-Ne laser. For this procedure, samples were first diluted in particle-free purified water, and the measurements were performed at 25ºC.

The degree of encapsulation was determined by size exclusion chromatography. Samples (500 μL) were loaded on a Sephadex LH-20 column (3.5 cm in diameter with a column packing length of 17 cm) and eluted using purified water as the mobile phase. The eluted fractions were monitored by turbidity measurements at 410 nm using a FEMTO 800XI spectrophotometer (Sao Paulo, Brazil). Aliquots of 1 mL of each fraction were lyophilized then solubilized in 3 mL of methanol and assayed for $ZnPcSO_4$ content by spectrofluorimetry (λ_{exc} = 640 nm, λ_{em} = 730 nm), as described in spectrofluorimentric assay section. The encapsulation efficiency (EE) was calculated using the following equation:

$$EE = \frac{M1}{Mt} x100$$

where, *M*1 is the amount of $ZnPcSO_4$ encapsulated in the nanoparticles and *Mt* is the amount of $ZnPcSO_4$ used in the formulation. The experiments were performed in triplicate.

The lamellar nanodispersions not was evaluated in this research because it has been studied by ours research group and in the future it may be demonstrated as promising skin delivery enhancer of a several lipophilic and hydrophilic photosensitizers.

2.4. *In vitro* Skin Penetration Study

$ZnPcSO_4$ topical delivery systems were assessed in an *in vitro* model of porcine ear skin, as previously described [24] in order to evaluate the skin retention of $ZnPcSO_4$ from nanodispersions of MO-based liquid crystalline hexagonal and cubic phases and the corresponding cubic, lamellar and hexagonal phase bulk gels.

The skin of a freshly excised porcine ear was carefully dissected (ensuring that the subcutaneous fat was completely removed), dermatomized at 500 μm (Dermaton, Nouvag, Switzerland) and stored at -20º C. On the day of the experiment, the skin was mounted in a Franz diffusion cell (with a diffusion area of 0.8 cm^2) with the stratum corneum (SC) facing the donor compartment (where 100 μL of the test formulation was applied) and the dermis facing the receptor compartment, which was filled with 3.0 mL of receptor medium (100 mM phosphate buffer, pH 7.2 ± 0.2, containing 2% Polysorbate 80). The receptor phase was under constant stirring at 400 rpm and held at a 37° C (± 0.5) by a water jacket for 6 h. At the end of the experiment, skin surfaces were thoroughly washed with distilled water to remove excess formulation and carefully wiped with tissue paper. The whole skin samples were used for fluorescence microscopy analysis. Aliquots of receptor solution were assayed by spectrofluorimetric method for $ZnPcSO_4$.

2.5. Spectrofluorimetric Assay for $ZnPcSO_4$

$ZnPcSO_4$ present in the receptor solution and samples from size exclusion chromatography was assayed by spectrofluorimetry (λ_{exc} = 640 nm, λ_{em} = 730 nm) using a Hitachi F-4500 fluorescence spectrophotometer (Tokyo, Japan). Analytical method was developed and evaluated with respect to linearity, precision, accuracy, limits of detection (LOD), and lower limit of quantification (LLOQ). The linearity of the assay was determinate using methanolic standard solution with concentration ranging from 0.25–10.00 μg/mL, and the calibration curve was y=0.1447x+0.0025 (r=0.999). The error and accuracy of the method showed a variation coefficient not greater than 0.93% and 96%, respectively. The lower limits of quantification and detection of the method were 0.25 μg/mL and 0.08 μg/mL, respectively.

2.6. *In vivo* Skin Penetration Studies

These experiments were performed using six female hairless mice (strain HRS/J, Jackson Laboratories, Bar Harbor, ME, USA). One hundred microliters of MO-based hexagonal dispersion formulation was applied to the skin on the dorsal region of the hairless mice over an area of 1.5 cm^2, delimited by a template. After 6 h of application, the animals were euthanized with carbon dioxide vapor following the protocol previously authorized by the University of São Paulo Animal Care and Use Committee (Authorization number: 10.1.160.53.0), and the treated skin regions were dissected.

2.7. Visualization of Cutaneous Penetration of Photosensitizer by Fluorescence Microscopy

The skin samples obtained from the *in vitro* and *in vivo* experiments were embedded in a matrix of Tissue-Tek® O.C.T.™ compound (Sakura, Zoeterwoude, The Netherlands), frozen at -17ºC and sectioned to the skin surface into vertical slices 40 μm thick using a cryostat (CM 1900, LEICA, Nussloch, Germany). The presence of $ZnPcSO_4$ and its distribution in the skin layers was visualized by fluorescence microscopy (Axioskop 2 plus, Carl Zeiss, Göttingen, Germany) using 640 nm and 730 nm band-pass excitation and emission filters, respectively (filter Set 50, Carl Zeiss). Images were recorded with a light-sensitive charge-coupled device digital camera (AxioCam HR, Göttingen, Carl Zeiss) using identical sensitivity and exposure settings.

3. RESULTS

We investigated the enhanced skin penetration of a water-soluble zinc phthalocyanine provided by MO-based liquid crystalline formulations and their nanodispersions. Bulk gels of lamellar, cubic and hexagonal crystalline phases were initially identified by light microscopy with crossed polarizer, as well as the cubic and hexagonal phase dispersion systems. Polarized light microscopy observation showed patterned structures and birefringent textures of lamellar and hexagonal phases, such as the Maltese cross (Fig. **1A**) and an angular texture (Fig. **1B**), respectively. Photomicrographs of the nanodispersions of the cubic and hexagonal phases are shown in Fig. (**1C**) and (**1D**), respectively and it is in agreement with Lopes *et al*., 2007 [25].

The particle size distribution, zeta potential and polydispersity of both the cubic and hexagonal phase nanodispersions loaded with $ZnPcSO_4$ are listed in Table **1**. The light scattering analysis demonstrated the presence of nanosized particles with sizes of 224 ±10 nm and 188 ± 10 nm for the cubic and hexagonal nanodispersions, respectively. Both nanodispersion present negative zeta potential values, of which, hexagonal phase showed higher negative charge. The polidispersity index indicate monodispersed characteristic for both nanodispersions. The encapsulation degrees assessed by size exclusion chromatography were 50.1% and 38.5% (± 2) $ZnPcSO_4$ loading in the hexagonal and cubic nanodispersion systems, respectively.

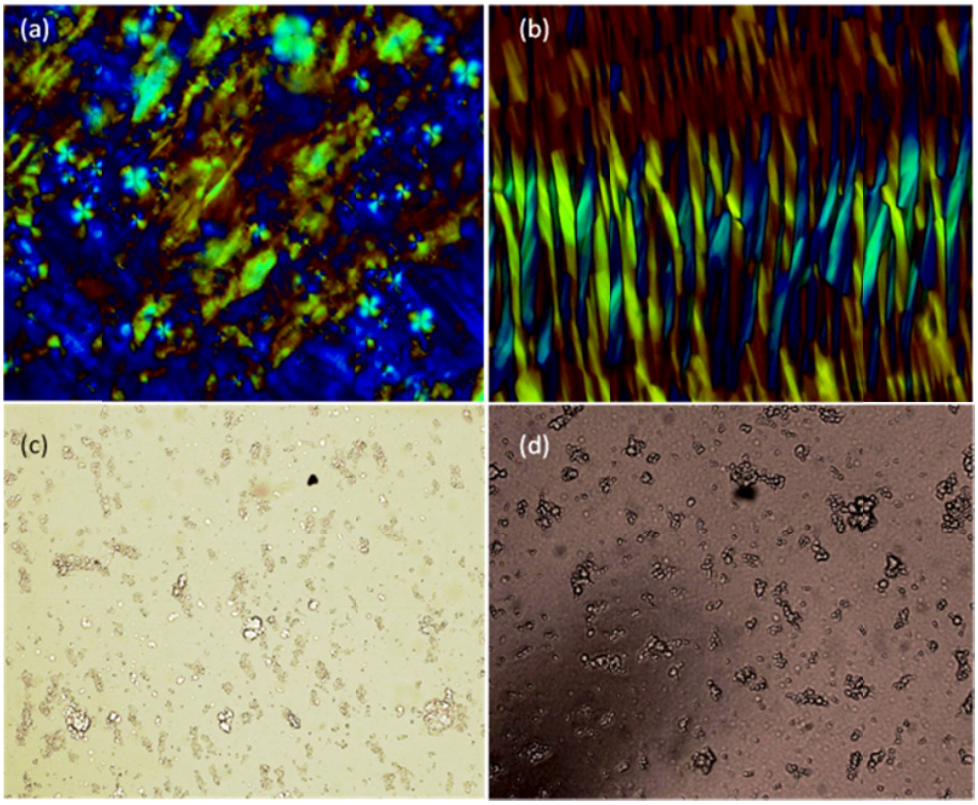

Fig. (1). Characterization of the liquid crystalline phases and their dispersions by polarized light microscopy. (**a**) Lamellar phase bulk gel; (**b**) hexagonal phase bulk gel; (**c**) cubic phase nanodispersion and (**d**) hexagonal phase nanodispersion.

Table 1. Caracterization of Cubic and Hexagonal Nanoparticles from Particle Size Distribution, Zeta Potencial and Polidispersity

Preparation	Particle Size Distribution	Zeta Potencial	Polidispersity*
Cubic nanodispersion	224 ±10 nm	-16.7 mV	0.37
Hexagonal nanodispersion	188 ±10 nm	-23.0 mV	0.21

* Polidispersity index, meaning the measurement of the homogeneity of a dispersion, ranging from 0.0 (monodisperse) to 1.0 (very heterogeneous).

In vitro $ZnPcSO_4$ skin penetration is illustrated in Fig. (**2**). After 6 h of application, the MO-based hexagonal nanodispersion system promoted a greater penetration of photosensitizer in the deeper skin layers (Fig. **2F**) compared with the cubic phase nanodispersion (Fig. **2E**) and the bulk crystalline phases, i.e., the lamellar (Fig. **2C**), cubic (Fig. **2C**) and hexagonal phases (Fig. **2D**).

Due to the improved penetration effect, the hexagonal nanodispersion was selected for a subsequent *in vivo* penetration study. (Fig. **3**) shows sections of untreated skin with and without fluorescence excitation (Fig. **3A** and **B**, respectively) and skin treated with the hexagonal nanodispersion system photographed immediately and 50 seconds after the application of the excitation light (Fig. **3C** and **3D**, respectively). The *in vivo* treatment with the hexagonal nanodispersion loaded with $ZnPcSO_4$ yielded an increased fluorescence in deeper skin layers. (Fig. (**3A**) and (**3B**)) are photomicrographs of untreated skin photographed without and with fluorescence excitation, respectively; a photomicrograph of skin treated with the hexagonal nanodispersion system was obtained in the same way (Fig. **3C**). No fluorescence was observed in the untreated skin (Fig. **3B**); however, the skin treated with the hexagonal nanodispersion system loaded with $ZnPcSO_4$ emitted a characteristic red light.

DISCUSSION

The water-soluble $ZnPcSO_4$ has shown high photodynamic efficiency and reduced phototoxic side effects in the treatment of brain and ocular tumors [18, 27]. However, there is a lack data for its application in topical PDT for skin cancer. Aqueous dispersions of liquid crystalline phases of MO were previously obtained and characterized [23], but the use of a hexagonal phase dispersion as a colloidal carrier of $ZnPcSO_4$ for topical PDT is a new application in this field. Here, we describe the preparation, characterization and skin uptake of $ZnPcSO_4$ delivered by a liquid crystalline phase MO nanodispersion.

Fig. (**1**) shows characteristic patterns of birefringent liquid crystalline phases under polarized light. The hexagonal phase displayed an angular texture [28]. The lamellar phase showed distinct woven structures and/or a mosaic or Maltese cross pattern, whereas the stiff transparent cubic phase was nonbirefringent [28, 29]. The presence of $ZnPcSO_4$ did not change the liquid crystalline structure of these phases.

Liquid crystalline nanodispersions have many important characteristics for drug delivery due to their drug solubilization capability

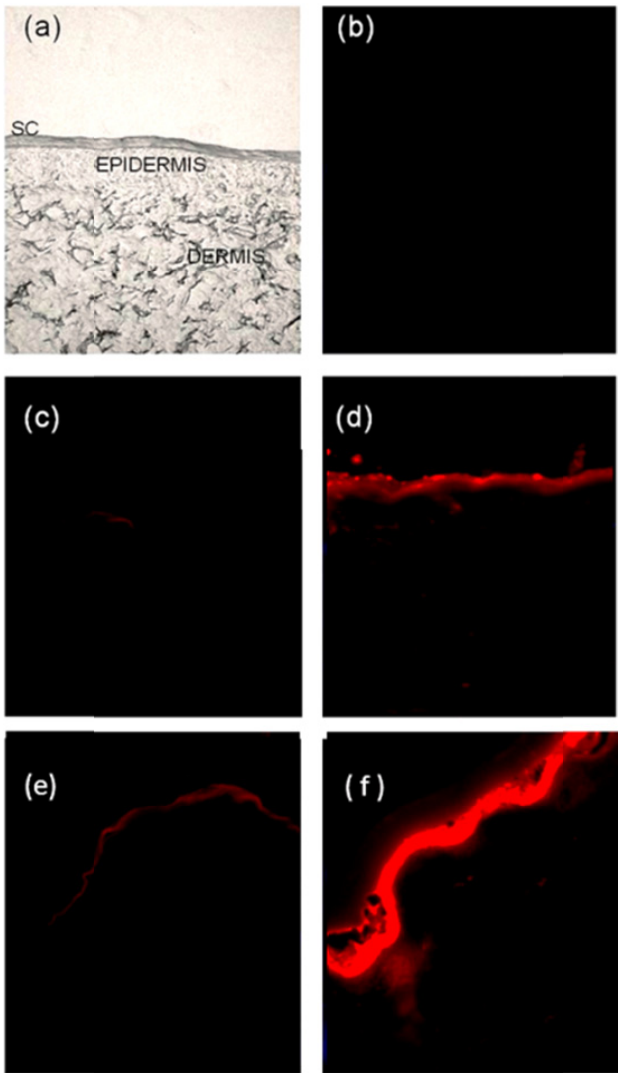

Fig. (2). Microscopic evaluation after *in vitro* skin treatment for 6 h using formulations loaded with $ZnPcSO_4$. (**a**) light microscopy of untreated skin section, (**b**) fluorescence microscopy of skin treated with lamellar phase bulk gel (absence of light), (**c**) fluorescence microscopy of skin treated with cubic phase bulk gel (absence of light), (**d**) fluorescence microscopy of skin treated with hexagonal phase bulk gel, (**e**) fluorescence microscopy of skin treated with cubic phase nanodispersion (low intensity of light) and (**f**) fluorescence microscopy of skin treated with hexagonal phase nanodispersions (high intensity of light). Sections were visualized using 640 nm (excitation) and 730 nm (emission) band-pass filters through a 10X objective.

and release properties, which can improve skin penetration by the drug [30]. The sonication of cubic and hexagonal phase with an excess of the aqueous phase to form nanodispersion systems resulted in milky and low-viscosity dispersions, as reported previously [15]. In order to evaluate the influence of poloxamer in cubic and hexagonal phase structures, the formulations were observed by polarized light microscopy before and after addition of poloxamer. The presence of poloxamer did not disrupt the cubic or hexagonal phase structures and additionally yielded a stable nanodispersion in the presence of photosensitizer. Increasing the poloxamer concentration to 1.5% in the hexagonal nanodispersion system caused a discrete reduction in particle size as determined by light scattering, which is in agreement with previously published results [31, 32].

Demonstrating the penetration-enhancing effect of MO, a previous study reported an increase of 5-aminolevulinic acid (5-ALA)

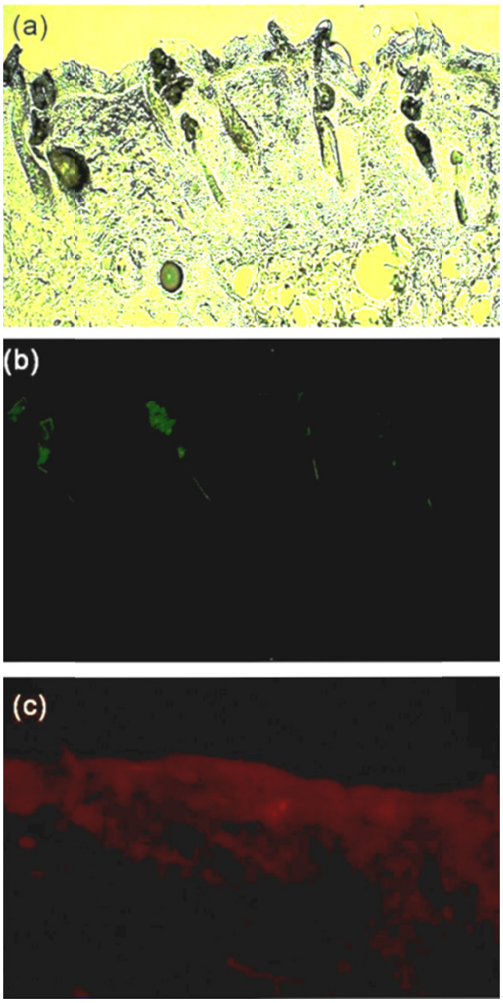

Fig. (3). Microscopic evaluation after *in vivo* skin treatment for 6 h using a hexagonal nanodispersion containing the photosensitizer. (**a**) Light microscopy of untreated skin, (**b**) fluorescence microscopy of untreated skin, (**c**) fluorescence microscopy of skin treated with the hexagonal nanodispersion. Sections were visualized using 640 nm (excitation) and 730 nm (emission) band-pass filters through a 10X objective.

in vitro penetration and *in vivo* protoporphyrin IX accumulation in hairless mouse skin with the use of various concentrations of MO in propylene glycol in comparison with the control solutions [32].

MO structured in a cubic phase gel (70:30, MO:water) provided an increase of *in vitro* and *in vivo* skin uptake for 5-ALA and its ester derivatives (hexyl, octyl and decyl esters), m-tetrahydroxyphenylchlorin and an *in vivo* increase of protoporphyrin IX accumulation [33]. Similarly, compared to standard ointments, a similar effect of *in vivo* protoporphyrin IX accumulation was observed when an MO cubic phase was used as a delivery vehicle for 5-ALA and methyl-5-ALA [13]. However, MO-based cubic and hexagonal phase nanodispersions remain an unexplored pathway to enhanced PDT for skin cancer, and only the influence of photosensitizers on their internal liquid crystalline structure was recently studied [15].

Although a prior study reported that cubic and lamellar phases provided the highest drug retention in the whole skin (epidermis plus dermis) in both *in vitro* and *in vivo* studies compared with the control formulation of a hydroxyethyl cellulose gel [19], in the present work, greater *in vitro* delivery of $ZnPcSO_4$ into the deeper skin layers was observed when the hexagonal nanodispersion sys-

tem was applied in comparison with the other liquid crystalline phases (Fig. **2**). Comparing the cubic and hexagonal phases, there are differences between these crystalline phases that may explain the present findings. The delivery of compounds into deeper skin layers has been shown to depend on the system used and the MO concentration; a higher delivery of vitamin K to the epidermis plus dermis was obtained using a nanodispersion of MO-based hexagonal phase when compared to a Vaseline solution [25], and MO, the main structural lipid of the nanodispersion, is a penetration enhancer that has already been demonstrated to increase skin penetration of peptide drugs such as cyclosporine in a concentration-dependent manner [24]. Alternatively, the presence of OA in the MO-based hexagonal nanodispersion system may have been responsible for the greater penetration of the photosensitizer into the deeper layers of skin when compared with the cubic phase nanodispersion, as the penetration-enhancing effect of OA is well known [16, 34]. Furthermore, the small particle size of the hexagonal phase nanodispersion should improve the partitioning of $ZnPcSO_4$ into the stratum corneum. *In vivo* penetration results showed higher fluorescence by $ZnPcSO_4$ in the deeper skin layers of hairless mice when the hexagonal phase nanodispersion was used (Fig. **3C**) compared with the control skin without treatment, indicating that a biodistribution of this photosensitizer in the epidermis and the deeper skin layers was achieved.

Considering the barrier effect of the stratum corneum and the limitations of $ZnPcSO_4$ in overcoming this barrier, the hexagonal phase nanodispersion provided a skin delivery system for this substance in a way that can enable its use in topical PDT. The results obtained encourage future studies to ascertain whether our formulations can improve the efficacy of topical PDT for skin cancer.

CONCLUSIONS

Nanodispersions of MO-based liquid crystalline hexagonal and cubic phases increased the *in vitro* skin penetration of $ZnPcSO_4$, more than the corresponding cubic, lamellar and hexagonal phase bulk gels.

Our results provide the possibility of a new application for $ZnPcSO_4$, improving the effectiveness of photodynamic therapy by utilizing a nanosized dispersion based on MO-liquid crystalline phases to deliver photosensitizing drugs into the deeper skin layers, where cancer and non-neoplastic diseases occur. Further studies will evaluate the photodynamic efficiency and phototoxic side effects in topical PDT and photodiagnostic assays for skin cancer using skin tumor cell lines and animal models of skin cancer.

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CONFLICT OF INTEREST

None declared.

REFERENCES

[1] Donnelly, R.F.; McCarron, P.A. and Woolfson, D. Drug Delivery Systems for Photodynamic Therapy. *Rec. Pat. Drug. Deliv. Formul.*, **2009**, *3*, 1-7.

[2] Choudhary, S.; Nouri, K.; Mohamed L. Elsaie. Photodynamic therapy in dermatology: a review. *Lasers. Med. Sci*., **2009**, *24*, 971-980.

[3] Medina W.S.; dos Santos N.A.; Curti C.; Tedesco A.C.; dos Santos A.C. Effects of zinc phthalocyanine tetrasulfonate-based photodynamic therapy on rat brain isolates mitochondria. *Chem. Biol. Interact*., **2009**, *179*, 402-406.

[4] Allison, R.R.; Sibata, C.H. Oncology photodynamic therapy photosensitizers: a clinical review. *Photodiagn. Photodyn. Ther.,* **2010**, *7*, 61-75.

[5] De Campos Araújo, L.M.P.; Thomazine, J.A.; Lopez, R.F.V. Development of microemulsions to topically deliver 5-aminolevulinic acid in photodynamic therapy. *Eur. J. Pharm. Biopharm*., **2010**, *75*, 48-55.

[6] Nishiyama, N.; Morimoto, Y.; Jang, W-D.; Kataoka, K. Design and development of dendrimer photosensitizer-incorporated polymeric micelles for enhanced photodynamic therapy. *Adv. Drug. Deliv. Rev*., **2009**, *61*, 327-38.

[7] Dragicevic-Curic, N.; Scheglmann, D., Albrecht, V., Fahr, A. Development of liposomes containing ethanol for skin delivery of temoporfin: characterization and *in vitro* penetration studies. *Colloids Surf. B: Biointerfaces*., **2009**, *74,* 114-22.

[8] Roy, I.; Ohulchanskyy, T.Y.; Pudavar, H.E.; Bergey, E.J.; Oseroff, A.R.; Morgan, J.; Dougherty, T.J.; Prasad, P.N. Ceramic-based nanoparticles entrapping water-insoluble photosensitizing anticancer drugs: anovel drug-carrier system for photodynamic therapy. *J. Am. Chem. Soc*., **2003**, *125*, 7860-7865.

[9] Wieder, M.E.; Hone, D.C.; Cook, M.J.; Handsley, M.M.; Gavrilovic, J.; Russell, D.A. Intracellular photodynamic therapy with photosensitizer - nanoparticle conjugates: cancer therapy using a 'Trojanhorse'. *Photochem. Photobiol. Sci*., **2006**, *5*, 727-734.

[10] Ricci-Junior, E.; Marchetti, J.M. Preparation, characterization, photocytotoxicity assay of PLGA nanoparticles containing zinc (II) Phthalocyanine for photodynamic therapy use. *J. Microencapsul*., **2006**, *23*, 523-538.

[11] Casas, A.; Battah, S.; Di Venosa, G.; Dobbin, P.; Rodriguez, L.; Fukuda, H.; Batlle, A.; MacRobert, A.J. Sustained and efficient porphyrin generation *in vivo* using dendrimer conjugates of 5-ALA for photodynamic therapy. *J. Control. Release*, **2009**, *135*, 136-143.

[12] Dragicevic Curic, N.; Scheglmann, D.; Albrecht, V.; Fahr, A. Temoporfin - loaded invasomes: development, characterization and *in vitro* skin penetration studies. *J. Control. Release*, **2008**, *127*, 59-69.

[13] Bender, J.; Ericson, M.B.; Merclin, N.; Iani, V.; Rosen, A.; Engstrom, M. J. Lipid cubic phases for improved topical drug delivery in photodynamic therapy. *J. Control. Release*, **2005**, *106*, 350-360.

[14] Bender, J.; Jarvoll, P.; Nydén, M.; Engström, S. Structure and dynamics of a sponge phase in the methyl ±-aminolevulinate/ monoolein/ water/ propylene glycol system. *J. Colloid Interface Sci*., **2008**, *317*, 577-584.

[15] Rossetti, F.C.; Fantini, M.C.; Carollo, A.R.; Tedesco, A.C.; Bentley, M.V.L.B. Analysis of liquid crystalline nanoparticles by small angle X-ray diffraction: Evaluation of drug and pharmaceutical additives influence on the internal structure. *Pharm. Sci*., **2011**, *7*, 2849-2857.

[16] da Silva, E.R.; de Freitas, Z.M.F.; Gitirana, L. de B.; Ricci-Júnior, E. Improving the topical delivery of zinc phthalocyanine using oleic acid as a penetration enhancer: *in vitro* permeation and retention. *Drug Dev. Ind. Pharm*., **2011**, *5*, 569-575.

[17] Tomazini, M.V.; Souza, C. da S.; Garcia, S.B.; Tedesco, A.C. Topical photodynamic therapy with zinc phthalocyanine: evaluation of fluorescence intensity, skin absorption, skin histological and immunohistochemical changes in animal model. *Ann. Bras. Dermatol.*, **2007**, *82*, 535-541.

[18] Xu, D.; Ke, Y.; Jiang, X.; Cai, Y.; Peng, Y.; Li, Y. *In vitro* photodynamic therapy on human U251 glioma cells with a novel photosensitizer ZnPcS4-BSA. *Br. J. Neurosurg*., **2010**, *6*, 660-665.

[19] Garcia, F.S. ; Tedesco, A.C.; Collett, J.H ; Bentley, M.V.L.B. Topical Delivery System for ZnPcSO4 based on liquid crystalline phases for use in PDT of skin cancer. In: 31st Annual Meeting and Exposition of Controlled Release Society, 2004, Honolulu-hawai. Abstracts of 31st Annual Meeting and Exposition of Controlled Release Society. Honolulu, **2004**, *1*. 320-320.

[20] Souza, J.G.; Gelfuso, G.M.; Simão, P.S.; Borges, A.C.; Lopez, R.F. Iontophoretic transport of zinc phthalocyanine tetrasulfonic acid as a tool to improve drug topical delivery. *Anticancer Drugs*, **2011**, *8*, 783-793.

[21] Rossetti, F.C. ; Lopes, L.B. ; Carollo, A.R.H.; Thomazini, J.A.; Tedesco, A.C.; Bentley, M.V.L.B. A delivery system to avoid self-aggregation and to improve *in vitro* and *in vivo* skin delivery of a phthalocyanine derivative used in the photodynamic therapy. *J. Control Release.,* **2011**, *155*, 400-408.

[22] Chang, C.M.; Bodmeier, R. Low viscosity monoglyceride-based drug delivery systems transforming into a highly viscous cubic phase. *Int. J. Pharm*., **1998**, *173,* 51-60.

[23] Lopes, L.B. ; Ferreira, D.A. ; Paula, D. de ; Garcia, M.T.J. ; Thomazini, J.A. ; Fantini, M.C ; Bentley, M.V.L.B. Reverse hexagonal phase nanodispersion of monoolein and oleic acid for topical delivery of peptides: *in vitro* and *in vivo* skin permeation of cyclosporin *A. Pharm. Res.,* **2006**, *6*, 1332-1342.

[24] Lopes, L.B.; Collett, J.H.; Bentley, M.V.L.B. Topical delivery of cyclosporin A: an *in vitro* study using monoolein as a penetration enhancer. *Eur. J. Pharm. Biopharm*., **2005**, *60*, 25-30.

[25] Lopes, L.B.; Spereta, F.F.F.; Bentley, M.V.L.B. Enhancement of skin penetration of vitamin K using monoolein-based liquid crystalline systems. *Eur. J. Pharm. Sci.*, **2007**, *32*, 209-215.

[26] Yamashita, J.; Shiono, M.; Hato, M. New lipid family that forms inverted cubic phases in equilibrium with excess water: molecular structure-aqueous phase structure relationship for lipids with 5,9,13,17-tetramethyloctadecyl

and 5,9,13,17-tetramethyloctadecanoyl chains. *J. Phys. Chem. B.*, **2008**, *39*, 12286-12296.

[27] Huang, Y.; Xu, G.; Peng, Y.; Chen, S.; Wu, Y. Photodynamic effects of ZnPcS(4)-BSA in human retinal pigment epithelium cells. *J. Ocul. Pharmacol. Ther.*, **2009**, *3*, 231-238.

[28] Worle G. Drechsler, M.; Koch, M.H.J.; Siekmann, B.; Westesen, K.; Bunjes, H. Influence of composition and preparation parameters on the properties of aqueous monoolein dispersions. *Int. J. Pharm.*, **2007**, *329*, 150-157.

[29] Williams, A.C.; Barry, B.W. Penetration enhancer. *Adv. Drug Deliv. Rev.,* **2004**, *56*, 603-618.

[30] Gustafsson, J.; Ljusberg-Wahren, H.; Almgren, M.; Larsson, K. Submicron particles of reversed lipid phases in water stabilized by a nonionic amphiphilic polymer. *Langmuir*, **1997**, *13*, 6964-6971.

[31] Nakano, M.; Sugita, A.; Matsuoka, H.; Handa, T. 2001. Small angle X-ray scattering and 13C NMR investigation on the internal structure of "cubosomes". *Langmuir*, **2001**, *17*, 3917-392.

[32] Steluti, R.; De Rosa, F.S.; Collett, J.; Tedesco, A.C.; Bentley, M.V. Topical glycerol monooleate/propylene glycol formulations enhance 5-aminolevulinic acid *in vitro* skin delivery and *in vivo* protophorphyrin IX accumulation in hairless mouse skin. *Eur. J. Pharm. Biopharm.*, **2005**, *3*, 439-444.

[33] Turchiello, R.F.; Vena, F.C.B.; Maillard, P.H.; Souza, C.S.; Bentley, M.V.B.L; Tedesco, A.C. Cubic phase gel as a drug delivery system for topical application of 5- ALA, its ester derivatives and m-THPC in photodynamic therapy (PDT). *J. Photochem. Photobiol. B: Biol.*, **2003**, *70*, 1-6.

[34] Pierre, M.B.; Ricci, E. Jr.; Tedesco, A.C.; Bentley, M.V. Oleic acid as optimizer of the skin delivery of 5-aminolevulinic acid in photodynamic therapy. *Pharm. Res.*, **2006**, *2*, 360-366.

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