

## In vitro transdermal delivery of propranolol hydrochloride through rat skin from various niosomal formulations

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### Abstract

**Objective(s):** The purpose of the present study was to prepare and to evaluate a novel niosome as transdermal drug delivery system for propranolol hydrochloride and to compare the in vitro efficiency of niosome by either thin film hydration or hand shaking method.

**Materials and Methods:** Niosomes were prepared by Thin Film Hydration (TFH) or Hand Shaking (HS) method. Propranolol niosomes were prepared using different surfactants (span20, 80) ratios and a constant cholesterol concentration. In vitro characterization of niosomes included microscopical observation, size distribution, laser light scattering evaluation, stability of propranolol niosomes and permeability of formulations in phosphate buffer (pH=7) through rat abdominal skin.

**Results:** The percentage of entrapment efficiency (%EE) increased with increase in surfactant concentration in all formulations. Among them, F3 formulation (containing span80:cholesterol ratio of 3:1) showed the highest entrapment efficiency ( $86.74 \pm 2.01\%$ ), Jss ( $6.33 \mu\text{g}/\text{cm}^2 \cdot \text{h}$ ) and permeability coefficient ( $7.02 \times 10^{-3} \text{cm}/\text{h}$ ). By increasing the percentage of entrapment efficiency (resulting in increase in surfactant concentration), the drug released time is not prolonged. Among all the formulations, F4 needed more time for maximum drug release. Among these formulations, F4 was also found to have the maximum vesicle size as compared to other formulations. It was observed that niosomal suspension prepared from span 80 was more stable than span 20.

**Conclusion:** This study demonstrates that niosomal formulations may offer a promise transdermal delivery of propranolol which improves drug efficiency and can be used for controlled delivery of propranolol.

**Keywords:** In vitro, Niosomes, Propranolol hydrochloride, Transdermal delivery

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### Introduction

Transdermal delivery has many advantages over conventional methods of drug administration, because it avoids hepatic first-pass metabolism, potentially decreases side effects and improves patient compliance. Propranolol, a beta-adrenergic blocking agent used in the treatment of hypertension, is reportedly subjected to an extensive and highly variable hepatic first-pass metabolism following oral administration (1,3).

Controlled administration of propranolol via transdermal delivery system could improve its systemic bioavailability and therapeutic efficacy by avoiding first-pass effect, as well as decreasing the dosing frequency required for treatment. This study investigates the *in vitro* skin permeation of propranolol delivery from niosomal preparation.

Niosomal drug delivery has been studied using various methods of administration (3) including intramuscular (4), intravenous (5), oral and transdermal (6,7). In addition, as drug delivery systems, niosomes have shown to enhance absorption of some drugs across cell membranes (8), localize drugs in targeted organs (9) and tissues and elude the reticuloendothelial system. Niosomes have been used to encapsulate colchicines (10), estradiol (11), tretinoin (12,13), dithranol (14,15) enoxacin (16) and for application such as anticancer, anti-tubercular, anti-leishmanial, anti-inflammatory, hormonal drugs and oral vaccine (4,5,8,17-22). Niosomes are preferred over other vesicular systems as they offer some advantages (23, 24) as following: it provides water-based vehicle suspension. offering better patient compliance in comparison with oily dosage forms. They possess an infrastructure consisting of hydrophilic, amphiphilic and lipophilic moieties which can accommodate drug molecules with a wide range of solubilities. The characteristics of the vesicle formulation are variable and controllable. Altering vesicle composition,

size, lamellarity, tapped volume, surface charge and concentration can control the vesicle characteristics. The vesicles may act as a depot, releasing the drug in a controlled manner. Other advantage of niosomes includes their osmotically active and stable structures as well as their tendency to increase the stability of entrapped drug. Handling and storage of surfactants requires no special conditions. They improve oral bioavailability of poorly absorbed drugs and enhance skin penetration of drugs. They can be made to reach the site of action by oral, parenteral as well as topical routes. The surfactants are biodegradable, biocompatible and non-immunogenic. They improve the therapeutic performance of the drug molecules by delayed clearance from the circulation, protecting the drug from biological environment and restricting effects to target cells. Niosomal dispersion in an aqueous phase can be emulsified in a non-aqueous phase to regulate the delivery rate of drug and administer normal vesicle in external non-aqueous phase.

### Materials and Methods

#### Materials

Propranolol was purchased from Daropakhsh Pharmaceuticals Company, Iran; Spans (20, 80), cholesterol, diethyl ether and methanol were obtained from Merck Chemical Industries, Germany. All chemicals and solvents were of analytical grade.

#### Methods

##### Preparation of niosomes

Niosomes were prepared by thin film hydration method using different grades of surfactants (span 20 & 80) and cholesterol in constant ratio as the composition shown in Table 1. The surfactants and cholesterol were dissolved in diethyl ether and solvent was then evaporated under reduced pressure using rotary flash evaporator (super fit rotary vacuum) at 150 rpm for 5-10 min. This intermittent vortexing at 50°C results in deposition of thin layer of solid mixture on the sides of the flask.

**Table 1.** percentage drug Entrapment Efficiency (%EE) of selected niosomal formulations (mean  $\pm$  S.D, n=3).

Formulation	(%EE)
F1	77.05 $\pm$ 1.22
F2	81.19 $\pm$ 1.09
F3	86.74 $\pm$ 2.01
F4	62.01 $\pm$ 1.85
F5	66.85 $\pm$ 1.66
F6	70.99 $\pm$ 0.97

Then it was hydrated with aqueous phase containing the drug (1 mg/ml) in 40 ml of distilled water, vortexed and heated at 60-70°C for 1 hour. The resulting multilamellar vesicles were cooled in an ice bath and sonicated by using probe type Ultrasonicator (Elma, Germany) for 3 min at 150V for preparing of unilamellar vesicles of niosomes. These niosomal vesicles are stored at 4°C in a refrigerator. Plain niosomes, as control for each formulation, were prepared without the drug using the same procedure (25).

#### **Entrapment efficiency percentage (%EE)**

Percentage of entrapment efficiency was determined by centrifuge method. A niosomal suspension (15 ml) was centrifuged at 2000 rpm for 30 min at 4°C.

The supernatant liquid was diluted with phosphate buffer (pH=7) and was assayed by UV spectrophotometry at 289 nm (26). The percentage of drug encapsulation was calculated by the following equation:

$$EE (\%) = [(C_t - C_f)/C_t] \times 100$$

Where  $C_t$  is the concentration of total drug and  $C_f$  is the concentration of untrapped drug.

#### **Stability of propranolol niosomes**

The samples were stored at 4°C and 25°C for 8 weeks and stability and drug content per gram of all samples were determined after 8 week (27).

#### **Animal experiments**

Male adult Albino Wistar rats (weighing 150-200 g and aged 10-12 weeks) were obtained from Animals Laboratory, Ahvaz Jundishapur University of Medical Sciences. The hair on the abdominal skin was removed with an electric clipper, taking care not to damage the skin. The rats were anaesthetized with ether prior to sacrificing them. Abdominal full-thickness skin was removed and any extraneous subcutaneous fats cleaned from the dorsa side using cooled acetone solution. Whole skin thickness was measured using a digital micrometer (AAOC, France).

#### **Vesicle size determination**

Mean size of niosomal formulations were measured at 25°C by photon correlation spectroscopy, Scatterscop particle size analyzer (Malvern-Korea). Light scattering was monitored at 25°C at a scattering angle of 90°.

#### **Scanning Electron Microscopy(SEM)**

The prepared niosomes size and shape was studied using SEM. The niosomes prepared by thin film hydration method were mounted on an aluminum stub with double-sided adhesive carbon tape. The vesicles were then sputter-coated with silver using a vacuum evaporator and examined with the scanning electron microscope (LEO, VP 1455- Germany) (Figure1).

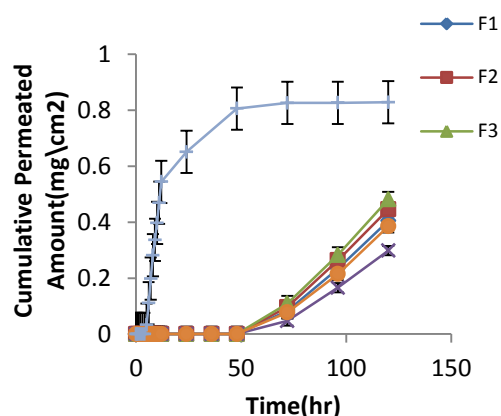
#### **In vitro skin permeation studies**

In vitro skin permeation of propranolol niosomes were studied using modified vertical Franz-diffusion cells with an effective diffusion area of approximately 3.46 cm<sup>2</sup>.

Full thickness Albino Wistar rat skin was placed securely between donor and receptor compartment with the epidermis site facing the donor compartment.

The receptor compartment was filled with 20 ml phosphate buffer (pH=7) solution

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**Figure 1.** Scanning Electron Microscopy (SEM) photographs of F4 formulation.

which was continuously stirred with a small magnetic bead at 300 rpm and thermo stated at  $37\text{C}^{\circ} \pm 1\text{C}^{\circ}$  throughout the experiment.

After 16 hr equilibrium, 3 g of propranolol niosomal were placed on to the skin surface. At predetermined time intervals (0.5, 1, 2, 3,....., 120 h) a 2 ml of sample was withdrawn and replaced with an equal volume of fresh phosphate buffer(pH=7) solution to ensure sink conditions.

### Statistical analysis

All data are expressed as mean  $\pm$ SD. Statistical comparison was made using one-way ANOVA and  $p < 0.05$  was considered statistically significant.

## Results

### Entrapment efficiency percentage (%EE)

The percentage of entrapment efficiency of all formulations was found to be in decreasing order of  $F_3 > F_2 > F_1 > F_6 > F_5 > F_4$ . EE (%) of different formulations are shown in (Table1).

In niosomal formulations prepared using sorbitan monoesters, span 80 showed the maximum entrapment efficiency at 3:1 (surfactant:cholesterol) molar ratio.

### Vesicle size determination

The vesicle size was found in the range of  $3.1 \mu\text{m}$  to  $35.35 \mu\text{m}$  as shown in Table 2. The vesicle size of propranolol niosomal formulation was found to be in decreasing order of  $F_4 > F_5 > F_6 > F_1 > F_2 > F_3$ . Among

these formulations,  $F_4$  was found to have maximum vesicle size and  $F_3$  have minimum vesicle size as compared to other formulations.

### Stability study

Stability studies were performed on  $F_1$  and  $F_4$  niosomal formulations for a period of 8 weeks by subjecting them to aging at  $4^{\circ}\text{C}$ . Indirect relationship between the entrapment efficiency of the drug in the vesicles and aging was observed.

As the storage period increased, the degree of entrapment efficiency decreased. It was observed that formulations prepared by span 80 were more stable than niosomes prepared by span 20.

Also, niosomal suspensions were more stable in  $4^{\circ}\text{C}$  than  $25^{\circ}\text{C}$ . The results are shown in Table 3.

### In vitro permeation studies

The results of in vitro skin permeation are shown in Table 4.

Permeation profiles of propranolol hydrochloride through the excised rat skin from the niosomal formulations and control is shown Figure 2.

The results showed in Figure (2) and tabulated in Table (3) indicate that the propranolol permeation through rat skin in successfully controlled.

The results indicate that all niosome formulations decreased the permeability across rat skin compared with control. While propranolol is released from the water drug solution (control sample) and permeated completely in less than 3 hrs, niosomal formulations were able to delay the process up to 62.38 h. Formulations  $F_4$  and  $F_3$  showed the minimum and maximum  $J_{SS}$ , respectively, with a range of  $3\text{-}6.33 \mu\text{g}/\text{cm}^2/\text{h}$  for all of the formulations. The  $J_{SS}$  values of all of the formulations were significantly less than that of control ( $p < 0.05$ ). The results of permeability coefficient (P) showed the maximum value of  $7.02 \times 10^{-3} \text{ cm}/\text{h}$  and a minimum of  $.03 \times 10^{-3} \text{ cm}/\text{h}$  for  $F_3$  and  $F_4$  samples, respectively.

**Table 2.** Compositions of selected niosome formulations and particle size (mean±SD, n=3).

Formulations	Surfactant	Drug	surfactant	Cholesterol	Particle Size(μm)	Poly dispersity Index (PDI)
F <sub>1</sub>	Surfactant 80	1mg/ml	3 g	3 g	16.51 ± 1.06	0.375±0.14
F <sub>2</sub>		1mg/ml	6 g	3 g	6.93 ± 2.15	0.389±0.05
F <sub>3</sub>		1mg/ml	9 g	3 g	3.10 ± 1.08	0.379±0.11
F <sub>4</sub>	Surfactant 20	1mg/ml	3 g	3 g	35.96 ± 2.91	0.395±0.08
F <sub>5</sub>		1mg/ml	6 g	3 g	30 ± 3.38	0.371±0.07
F <sub>6</sub>		1mg/ml	9 g	3 g	22.96 ± 2.59	0.383±0.021

There was a significant decrease in permeability coefficient (P) for all of the formulations when compared with control ( $p < 0.05$ ), indicating their ability to control drug permeation. There was also a significant increase in  $T_{Lag}$  for different formulations if compared with control ( $p < 0.05$ ), confirming their retarding properties.

### Discussion

Amongst many reported methods for the preparation of niosomes, thin film hydration method was selected since this method was able to encapsulate hydrophobic drug with higher entrapment efficiency and smaller particle size. The niosomal formulations with Tweens display poor entrapment with lipophilic or amphiphilic drugs whereas Spans give higher entrapment with high stability.

This is due to the fact that hydrophilic surfactants (such as Tweens) owing to high aqueous solubility do not form proper vesicular structure in aqueous medium, whereas due to more lipophilic nature, Spans form vesicles and entrap the lipophilic drug or amphiphilic drugs. Niosomes are composed of non-ionic surfactants which are biocompatible and relatively non-toxic and themselves serve as an excellent permeation enhancer (15).

In this study in order to assess the influence of the drug carrier on the diffusion of drug through skin, *in vitro* permeation studies (Figure 2), using stripped Albino Wistar rat skin and

vertical Franz diffusion cell was utilized. In the present study transdermal controlled permeability of propranolol hydrochloride molecule (water-soluble and low molecular weight (295.8 Da) drug was studied. One of the mechanism by which niosomes may contribute to transdermal drug delivery may be described to the fusion of vesicles on the surface of the skin and hence enhanced skin permeation (28, 29). Moreover, it has been proven that niosomes enhance penetration and retention of topically applied drug (30).

Niosomal propranolol formulations were designed to control drug transdermal permeation. The higher  $T_{Lag}$  of the formulations, it is expected that they may cause structural changes in skin layers and hence affect the drug distribution in different layers. The results also show that Span 80, a surfactant with HLB of 4.3, has increased loading efficiency in comparison to Span 20 (HLB=8.6). The reason may be the ability of more lipophilic surfactant (Span 80) which results in enhanced solubility of hydrophilic drug (propranolol) in lipid phase. Practically, increase of surfactant-lipid ratio has enhanced permeability rate of niosomal formulations. The average particle size of Span 80 formulations is also less than that of Span 20 containing samples. The minimum and maximum mean particle size was obtained for F<sub>3</sub> and F<sub>4</sub> formula, respectively, which is in accordance with their release and permeation results.

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**Table 3.** Physical stability of niosomal formulations at room (25°C) temperature and refrigerate (4°C) (Mean±SD, n=3).

Formulations	Storage Temperature	% Entrapment Efficiency		
		1st Day	3 weeks	8 weeks
F <sub>1</sub>	Room (25 <sup>0</sup> C)	61.04± 0.057	57.35 ± 0.066	51.42 ± 0.017
F <sub>1</sub>	Refrigerator (4 <sup>0</sup> C)	62.51± 0.023	61.49 ± 0.071	59.24 ± 0.013
F <sub>4</sub>	Room (25 <sup>0</sup> C)	59.73±0.099	50.07 ± 0.072	46.86 ± 0.028
F <sub>4</sub>	Refrigerator (4 <sup>0</sup> C)	60.27 ± 0.087	57.83 ± 0.068	54.98 ± 0.023

**Table 4.** *In Vitro* permeability parameters for propranolol hydrochloride and control ( Mean±SD, n=3).

Formulations	J <sub>SS</sub> (µg/cm <sup>2</sup> .h)	T <sub>Lag</sub> (hr)	D(cm <sup>2</sup> .h <sup>-1</sup> )	P(cm/h)
F <sub>1</sub>	4.34 ± 0.015	58.33 ± 0.1	1.4 × 10 <sup>-5</sup> ± 3.06 × 10 <sup>-7</sup>	5.94 × 10 <sup>-3</sup> ± 0.007
F <sub>2</sub>	5.3 ± 0.011	56.16 ± 3.92	1.45 × 10 <sup>-5</sup> ± 9.87 × 10 <sup>-7</sup>	6.72 × 10 <sup>-3</sup> ± 0.003
F <sub>3</sub>	6.33 ± 0.012	51.26 ± 2.02	1.59 × 10 <sup>-5</sup> ± 6.24 × 10 <sup>-6</sup>	7.02 × 10 <sup>-3</sup> ± 0.009
F <sub>4</sub>	3 ± 0.001	62.38 ± 5.6	1.31 × 10 <sup>-5</sup> ± 1.21 × 10 <sup>-6</sup>	5.03 × 10 <sup>-3</sup> ± 0.001
F <sub>5</sub>	3.660 ± 0.017	57.68 ± 9.6	1.44 × 10 <sup>-5</sup> ± 2.35 × 10 <sup>-6</sup>	5.9 × 10 <sup>-3</sup> ± 0.004
F <sub>6</sub>	4.66 ± 0.01	51.14 ± 3.4	1.6 × 10 <sup>-5</sup> ± 1.14 × 10 <sup>-6</sup>	6.58 × 10 <sup>-3</sup> ± 0.005
Control	6.066 ± 0.009	3.01 ± 1.08	2.91 × 10 <sup>-4</sup> ± 8.69 × 10 <sup>-5</sup>	0.02 ± 0.0036

It can be suggested that along with decrease in particle size, the surface area of particles increase and subsequently release and permeation increase. Figure 1 shows the SEM images of F<sub>4</sub> niosomal formulation. According to the results, niosomal formulations caused a reservoir effect for drug that lead to the drug entrapment in niosomal composition and also skin layers and therefore showed a retardation effect. Other words, niosomes have lowered diffusion coefficient (D) and hence their P and J<sub>SS</sub> indices. Ruckmani et al have also previously reported retardation in cytarabine hydrochloride release for niosomal formulations containing sorbitan ester/cholesterol or polyoxyethylene sorbitan esters/cholesterol (20).

Comparing their results with our findings, it could be suggested that high molar ratio of cholesterol can significantly lower the release rate of propranolol HCl.

Our findings are in accordance with Bisby et al study that reported the effect of

cholesterol concentration on release of calcein from niosomal formulations.

Their results showed that increasing the cholesterol molar control content to more than 5% was considerably decreased the drug release (31). It is generally accepted that higher surfactant ratio increases hydrophilic drug solubility in lipid phase, cholesterol, the drug affinity to the vehicle, and therefore enhances their entrapment efficacy. Another suggested mechanism is lowering the size average of particles, increasing the surface area and hence enhancing their loading and permeability properties (33). The results of permeation study are evidences for such mechanisms. There have been the most rapid release and permeation for F<sub>3</sub> which had the minimum particle size and the maximum loading index. On the contrary, F<sub>4</sub> that had the largest particle size and minimum loading efficacy, showed a considerable delay in drug release and permeation. Also, due to relatively higher lipophilicity of external skin layers, i.e.

stratum corneum, more lipophilic vehicle prepared from Span 80 have more readily penetrated into the skin, interacted with skin constituents followed by the release of their drug content, a phenomenon that may not be considered for Span 20 containing formulations.

Therefore, it may be concluded that niosomal formulations of propranolol HCl are able to reduce P and  $J_{SS}$  coefficients by decreasing diffusion coefficient.

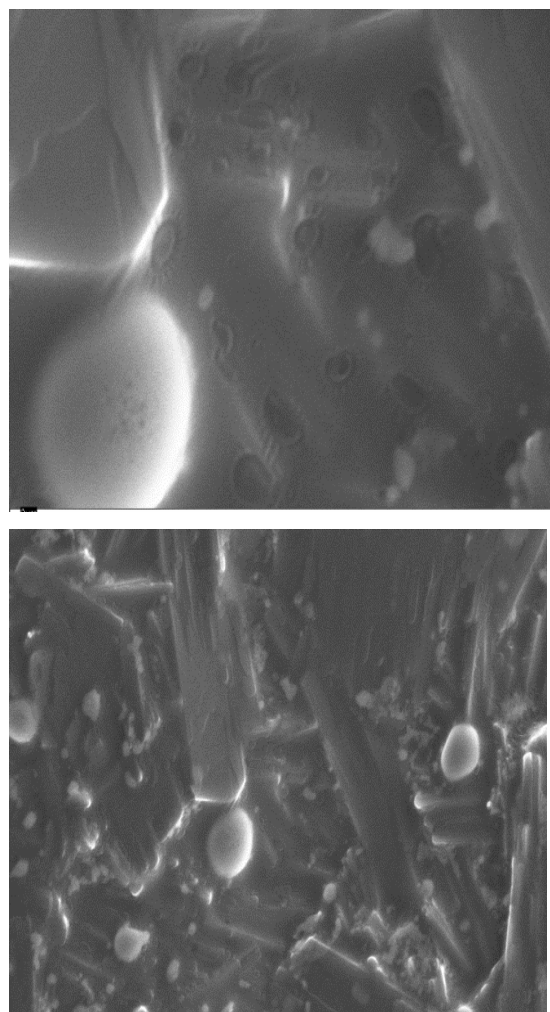
The proposed mechanisms are the reservoir effect and retention capacity of niosomes. The effect is a concentration-dependent phenomenon. In other words, the more molar ratio of surfactant, the higher diffusion coefficient followed by P and  $J_{SS}$  enhancement. The effect of surfactants is due to disruption of lipid bilayer in the stratum corneum (34).

### Conclusions

Thin film hydration method used for the preparation of propranolol niosomes was found to be a proper technique to encapsulate hydrophobic drug in non-ionic surfactants. The non-ionic surfactant prepared showed reasonable drug entrapment, suitable size and good controlled drug permeability. In this work, niosomes were prepared by variable surfactant and constant cholesterol concentrations. The impact of surfactant and cholesterol in the entrapment efficiency and release rate was significant.

From this work, it is concluded that by increasing surfactant concentration entrapment efficiency increases. Among all the formulations, F<sub>3</sub> formulation (with span 80 & cholesterol ratio 3:1) showed highest entrapment efficiency of  $86.74 \pm 2.01\%$ . It was observed that niosomal formulation prepared from span 80 was more stable than that of span 20.

Also, all of the niosomal formulations were more stable in refrigerator temperature than room temperature.



**Figure 2.** Permeation profiles of propranolol hydrochloride through the excised rat skin from the niosomal formulations and control.

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### References

1. Midha K K, Roscoe R M, Wilson W, Cooper J K. *Biopharm. Drug Dispos.* 1983; 4: 331-338.
2. Walle T, Fagan T, Conrad E, Walle U K, Gafney T. *Clin. Pharmacol. Ther.* 1976; 26: 167-172.
3. Routlage P A, Shand D G. *Clin. Pharmacokintic.* 1979; 4:73-90.

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- Blazek-Welsh. A I, Rhodes D G. Maltodextrin-based proniosomes, *AAPS Pharm.Sci.*2001; 3: E1.
- Arunothayanun .P,Turton .J.A, Uchehgbu .I.F, Florence .A.T, Preparation and in vitro in vivo evaluation of luteinizing hormone releasing hormone (LHRH)-loaded polyhedral and spherical tubular niosomes, *J. Pharm. Sci.* 1999; 88: 34-38.
- Uchehgbu .I.F, Double .J.A, Turton .J.A, Florence .A.T, Distribution, metabolism and tumoricidal activity of doxorubicin administered in sorbitanmonostearate (Span 60) niosomes in the mouse, *Pharm. Res.*1995; 12: 1019.
- Yoshioka .T, Sternberg .B, Florence .A.T, Preparation and Properties of Vesicles (Niosomes) of Sorbitan Monoesters (Span-20, Span-40, Span-60 and Span-80) and A SorbitanTriester (Span-85).*Int. J. Pharm.* 1994; 105: 1-6.
- Lasic .D.D, *Liposomes: from physics to application* Elsevier, Amsterdam, New York; 1993.
- Hao .Y, Zhao .F, Li .N, Yang .Y, Li .K, Studies on a high encapsulation of colchicine by aniosome system, *Int. J. Pharm.* 2002; 244: 73-80.
- Fang .J.Y, Yu .S.Y, Wu .P.C, Huang .Y.B, Tsai .Y.H, In vitro skin permeation of estradiol from various proniosome formulations, *Int. J. Pharm.* 2001; 215: 91-99.
- Manconi .M, Sinico .C, Valenti .D, Loy .G, Fadda .G.A.M, Niosomes as carriers for tretinoin.I. preparation and properties, *Int. J. Pharm.* 2002; 234: 237-248.
- Manconi .M, Valenti .D, Sinico .Lai .C.F, Fadda .G.A.M, Niosomes as carriers for tretinoin II.Influence of vesicular incorporation on tretinoinphotostability, *Int. J. Pharm.*2003; 260: 261-272.
- Touitou .E, Junginger .H.E, Weiner .N.D, Nagai .T, Mezei .M, Liposomes as carriers for topical and transdermal delivery, *J. Pharm. Sci.* 1994; 83: 1189-1203.
- Agarwal .R, Katare .O.P, Vyas .S.P, Preparation and in vitro evaluation of liposomal/niosomal delivery systems forcutaneous drug dithranol, *Int. J. Pharm.* 2001; 228: 43-52.
- Fang .J.Y, Hong .C.T, Chiu .W.T, Wang .T.T, Effect of liposomes and niosomes on skin permeation of enoxacin, *Int. J. Pharm.* 2001; 219: 61-72.
- Udupa .N, Chandraprakash .K.S, Umadevi .P, Pillai .G.K, Formulation and evaluation of methotrexate niosomes, *Drug Develop.Ind. Pharm.*1993; 19: 1331-1342.
- Parthasarathi .G, Udupa .N, Umadevi .P, Pillai .G.K, Niosome-encapsulated vincristine sulfate: improved anticancer activity with reduced toxicity in mice, *J. Drug Targ.* 1994; 2: 173-182.
- Jain .C.P, Vyas .S.P, Preparation and characterization of niosomes containing rifampicin for lung targeting, *J. Microenc:* 1995; 12: 401-407.
- Williams .D.M, Carter .K.C, Baillie .A.J, Visceralleishmaniasis in the BALB/c mouse: a comparison of the in vivo activity of five nonionic surfactant vesicle preparations of sodium stibogluconate, *J. Drug Targ.*1995; 3: 1-7.
- Rentel .C.O, Bouwstra .J.A, Naisbett .B, Junginger .H.E, Niosomes as a novel peroral vaccine delivery system, *Int. J. Pharm.* 1999; 186: 161-167.
- Ruchmani K., Jayakar B., Ghosal S.K. Nonionic surfactant vesicles (niosomeof cytarabine hydrochloride for effective treatment of leukemias:encapsulation, storage, and in vitro Release, *Drug Development &IndustrialPharmacy*, 2000, 26: 217-222.
- Small .D.M, *Handbook of lipid research: The physical chemistry of lipids, from alkanes to phospholipids*, first ed., Plenum Press, New York.1986 ; 4.
- Uchehgbu .I.F, Vyas .S.P, Non-ionic surfactant based vesicles (niosomes) in drug delivery, *Pharmaceutics* 2. 1998. p.33-70.
- Patel .R.P, Niosome: An unique drug delivery system, *Pharmainfo. net.*2007; 6 (5):1.
- Joseph .N.M, Niosomes in Targeted Drug Delivery: Some recent advances, *Int. J. Pharm. Sci. Res.*2010; 1(9): 1-8.
- Chengjlu Hu, David .G Rhodes, Pro niosomes, A novel drug carrier preparation, *International Journal of Pharmaceutics.*2006; 206: 110-122.
- Nagarsenker MS, Londhe VY, Nadkarni GD. Preparation and evaluation of liposomal formulation of tropicamide for ocular delivery , *Int. j. pharm.*1999; 190: 63-71.
- Balakrishnan P, Shanmugam S, Lee WS, Lee W M, Kim J O, Oh DH, et.al. Formulation and in-vitro assessment of minoxidilniosomes for enhanced skin delivery, *Int. J. Pharm.* 2009; 377: 1-8.
- Uchehgbu IF, Vyas SP. Non-ionic surfactant based vesicle (niosomes) in drug delivery, *Int. J.Pharm.*1998; 172: 33-70.
- Touitou E, Junginger HE, Weiner ND, Nagai T, Mezei M. Liposomes as carriers



- for topical and transdermal delivery, *J. Pharm. Sci.* 1994; 83: 1189-1203.
31. Van H D, Vanrensen A, Devringer T, Junginger H, Bouwstra J. Diffusion of estradiol from nonionic surfactant vesicles through human stratum corneum in-vitro, *STP Pharm. Sci.* 1996; 06: 72-78.
  32. Bisby R.H., Mead C., Morgan C.H. Photosensitive liposomes as “cages” for laser-triggered solute delivery: the effect of bilayer cholesterol on kinetics of solute release. *FEBS Letter*, 1999, 463: 165-168.
  33. Jigar V, Puja V, Krutika S. Formulation and evaluation of topical niosomal gel of erythromycin 2011; 3: 123-126.
  34. Barry BW. Mode of action of penetration enhancers in human skin, *J Control Release*. 1987; 6: 85-97.