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PREPARATION AND *IN VITRO* CHARACTERIZATION OF MUCOADHESIVE PROGESTERONE -EGG ALBUMIN MICROSPHERES FOR NASAL ADMINISTRATION

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ABSTRACT

In the undertaken study cross linked egg albumin microspheres of progesterone (PG) have been investigated through the nasal route. A smooth, spherical, cross-linked egg albumin microsphere in the size range of 15-37 μm loaded with progesterone were prepared by multiple emulsion (o/w/o) method by glutarldehyde cross-linking and thermal denaturation techniques. Microspheres were prepared by using different drug/polymer ratios. Egg albumin was used as a mucoadhesive polymer in the formulation to increase the residence time of the microspheres on the nasal mucosa. The albumin microspheres were characterized and evaluated with respect to the particle size, production yield, encapsulation efficiency, shape and surface properties, drug polymer interaction, mucoadhesive property and suitability for nasal drug delivery. The effect of process variables on particle size of microspheres was also studied. Shape and surface morphology were examined using scanning electron microscopy. Placebo microspheres exhibited the smooth surface while the incorporation of drug imparted a slight roughness to the surface. Optimized process and formulation parameters resulted in spherical shape and rigid surface, homogenous population of microspheres in the size range of 15.56 ± 37. 31 μm. The *in vitro* diffusion of PG from the prepared microspheres exhibited the extent of drug release decreased from 91–69%. The release of the drug has been controlled by swelling control release mechanism. No initial burst release has been recorded except for PG microspheres stabilized by using 25% w/v glutarldehyde as cross-linking agent. Modeling drug release from polymeric controlled drug delivery systems has led to a wide spectrum of mathematical models. The drug release from PG microspheres obeys Krosmeyer-Peppas model and non-Fickian diffusion pattern. Among the system examined glutaraldehyde cross linked microspheres show the highest release rate while the thermally cross linked microspheres had the lowest release rate, which is characterized by the longest lasting anomalous transport mechanism.

Key words: Mucoadhesive microspheres, Nasal drug delivery, multiple emulsion (o/w/o), Progesterone (PG), Egg albumin, Olive oil, Glutarldehyde cross-linking.

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INTRODUCTION

Progesterone is a lipophilic drug used to control reproductive function, habitual abortion, suppress or synchronize estrous and in postmenopausal therapy. Unlike synthetic progestin, progesterone is attractive for fertility control because it occurs in high concentration in natural conditions without any known side effects[1]. However, the oral delivery of progesterone is hampered since it is not tolerated in higher doses and its oral bioavailability is poor due to its intense hepatic metabolism and short biological half life. This greatly limits the efficacy of progesterone on per oral administration. The development of biodegradable polymeric delivery systems for antifertility steroids has received considerable attention in past 20 years[2-5].

The pharmacological approach to fertility control is mainly by oral administration of steroids. Although controlled release system such as Progestart and Norplants, which deliver progesterone and levonorgestrel respectively from non-biodegradable polymer matrices have met with a reasonable of clinical success. The disadvantage of oral route is the requirement of daily ingestion and the subsequent daily variation in drug concentrations[6-9]. Implantable rods, fibers, films and injectable microspheres have been prepared from a number of synthetic biodegradable polymers. Injectable biodegradable drug reservoir from glutamic acid/leucine co-polymers in the forms of tubes and solid rods were prepared by Sidman et al.[10] to provide controlled release of progesterone. Lee et al.[11] incorporated progesterone into glutarldehyde cross-linked serum albumin microspheres and showed that an extended release of 1-2 ng/hr/mL of serum was possible for about 20 days. Albumin microcapsules and microspheres cross linked with glutarldehyde and 2, 3-butanedione were investigated for progesterone delivery by Oienti and Zecchi[12].

The potentiality of nasal route for the administration of antifertility has been also explored. Nasal cavity has certain obvious advantages of large surface area and highly vascularized epithelial. Nasal route also avoid first pass metabolism. It has been shown that the bioavailability of steroidal drugs when given via nasal route in rat is greatly superior to oral route[13-16].

However, there are some problems such as mucociliary clearance and low permeability of the nasal mucosa to some drugs that have a large influence on the efficiency of the nasal absorption of drugs[17-20]. Illum et al.[21] introduced mucoadhesive microsphere systems for nasal delivery and characterized them. The microspheres form a gel-like layer,

which is cleared slowly from the nasal cavity, resulting in a prolonged residence time of the drug formulation.

The objective of this study was to develop nasal mucoadhesive microspheres containing progesterone as model drug. If steroids can be delivered in a sustained release manner, it is possible to regulate fertility. The present study aims at the development of an effective delivery system for progesterone via nasal route with focus on kinetic aspects of *in vitro* drug release.

EXPERIMENTAL

Materials

Progesterone was procured as a gift sample from Famy Care, Pharmaceuticals, Navi Mumbai and liquid paraffin, glutarldehyde, olive oil, ether were purchased from Loba Chemical, Mumbai. All reagents used were of analytical reagent grade

Preparation of progesterone loaded egg albumin microspheres[12,22-26]

1. Albumin microspheres were prepared by a multiple emulsion method. Progesterone (40 mg) was dispersed in 1 mL olive oil. The dispersion was mixed with 2 mL of an aqueous solution containing 6% w/v egg albumin solution. The mixture was stirred for 20 minutes to produce o/w emulsion. The emulsion was added to 5 mL of olive oil and the mixture was stirred again for 4 minutes by using magnetic stirrer to obtain the corresponding o/w/o multiple emulsions.

2. From the dropping funnel, this mixture was added drop wise to olive oil with continuous stirring at 1000 rpm for 15 minutes.

3. The microspheres were stabilized by adding 0.1 mL of 25% w/v glutarldehyde solution with continuous stirring for 20 minutes or by adding emulsion system to the preheated olive oil (100 mL) at 125^{o}C drop wise with continuous stirring for 30 minutes.

4 The preparation was cooled to 20^{o}C centrifuged at 700 rpm and supernatant was decanted. Microspheres thus obtained were washed with liquid paraffin and twice with ether to get a free flowing and discrete product. The microspheres were then suspended in anhydrous ether and stored at 5^{o}C in an airtight container.

Characterization of microspheres[22-26]

Particle size analysis

Particle size analysis is carried out by using a compound microscope. Dried microspheres were first redispersed in distilled water and placed on a glass slide and the number of divisions of the calibrated eye piece was counted by a using a stage micrometer. The particle diameters of more than 200 microspheres were measured randomly. The average particle size was determined by using Edmundson's equation.

$$D_{mean} = \sum nd / \sum n$$

Where n = Number of microspheres checked;
d = Mean size.

Median size of the microspheres formulations ranged from 15 to 37 μm was considered to be suitable for nasal administration.

Determination of microsphere density

The density of dried microspheres was determined at 25ºC using a specific gravity bottle and benzene (density 0.874 g/mL) as the medium in which practically no swelling of egg albumin microspheres was noted.

Encapsulation efficiency

To calculate the entrapment efficiency of progesterone into the microspheres, a weighed quantity of microspheres (20 mg) was determined by extracting into phosphate buffer (pH 6.8). Microspheres were crushed and powdered by using pestle and mortar and accurately weighed amount of this powder was extracted into phosphate buffer pH 6.8 by stirring at 600 rpm for 1 hour. The solution was filtered; suitable dilutions were made and estimated the drug content spectrophotometrically at 241 nm. Efficiency of drug entrapment for each batch was calculated in terms of percentage drug entrapment (PDE) as per the formula given below. Corresponding drug concentrations in the samples were calculated from the calibration plot generated by regression of the data taken in triplicate.

$$\% \text{ Drug entrapment} = \frac{\text{Actual drug content}}{\text{Theoretical drug content}} \times 100$$

Percentage yield

The prepared microspheres were collected and weighed. The yield was calculated for each batch. The percentage yield of microspheres was calculated as follows.

$$\% \text{ Yield} = \frac{\text{Weight of microspheres}}{\text{Theoretical weight of drug and polymer}} \times 100$$

Morphology

The surface morphology of the microspheres was observed by means of scanning electron microscopy. The samples were prepared by gently sprinkling the microspheres on a double adhesive tape. The microspheres were mounted in metal stubs using a double-sided adhesive tape. After being vacuum coated with a thin layer (100-150 Å) of gold, the microspheres were examined by SEM at different magnification using a 5-10 KV electron beam.

Infrared spectroscopy

About 1 mg of the microspheres was triturated with approximately 300 mg of dry, finely powdered potassium bromide Infrared (IR), the mixture was grinded thoroughly, spreaded uniformly in the die and compressed under vacuum at a pressure of about 800 Mpa. Mounted the resultant disc in a holder in the IR spectrophotometer and recorded the spectra in the IR region of 4000-625 cm^{-1}. The positions and the relative intensities of the absorption bands of the microspheres obtained were compared with that of the pure drug.

Compatibility studies

The pure drug and mixture of drug- albumin in the ratio of 1 : 1 were kept at room temperature for 30 days. Samples were subjected to FT-IR studies using KBr as a blank and the IR spectrum of pure drug and excipients mixtures were compared to find any interaction between drug and excipients used for formulation.

Mucoadhesion property

The *in vitro* mucoadhesion of microspheres was carried out by modifying the method described by Rao and Buri[27] using goat nasal mucosa. The dispersion (0.5 mL) of microspheres in water was placed on goat nasal mucosa after fixing to the polyethylene support. The mucosa was then placed in the desiccator to maintain at > 80% relative humidity at room temperature for 30 min to allow the polymer to hydrate and interact with the glycoprotein and also to prevent drying of the mucus. The mucosa was then observed under microscope, and the number of particles attached to the particular area was counted. After 30 min, the polyethylene support was introduced into a plastic tube cut in circular manner and held in an inclined position at an angle of 45^0. The mucosa was washed for 10

min with phosphate buffer pH 6.8 at the rate of 22 mL/min using a peristaltic pump; tube carrying solution was placed 2-3 mm above the tissue so that the liquid flowed evenly over the mucosa. Tissue was again observed under microscope to see the number of microspheres remaining in the same field.

The adhesion number was found by the following equation:

$$N_a = N/N_0 \times 100$$

Where N_a is adhesion number, N_0 is total number of particles in a particular area, and N is number of particles attached to the mucosa after washing area[28].

Swelling property

The swellability of microspheres in physiological media was determined by allowing the microspheres to swell in the phosphate buffered saline pH 6.8. 100 mg of accurately weighed microspheres were immersed in little excess of phosphate buffered saline of pH 6.8 for 24 hrs and washed thoroughly with deionised water[29]. The degree of swelling was arrived at using the following formula –

$$\alpha = W_s - W_o / W_o$$

Where α is the degree of swelling, W_o is the weight of microspheres before swelling and W_s is the weight of microspheres after swelling.

Bioadhesive strength

The bioadhesive strength of all batches was determined using modified pan balance device[30]. Section of nasal mucosa was cut from the goat nasal cavity and instantly secured with mucosal side out on glass vial. The vial using nasal mucosa was stored at 37ºC for 5 min. Next, one vial with a section of mucosa was connected to the balance and the other vial was placed on a height-adjusted pan. Microspheres were placed in between the adjusted vial. The weight was increased until two vials were detached. Bioadhesive force was determined for the minimum weight that detached the two vials

Effect of process variables on microsphere properties

PG microspheres were prepared with different drug to polymer ratio (1 : 2, 1 : 3, 1 : 4, 1 : 5) at temperature of 125ºC and agitation speeds of 1000 rpm. The effect of process variables on the properties of the resulting microspheres is depicted in Tables 1-3.

Table 1: Characterization of progesterone microspheres

Formulation code	Particle size (µm)	Product Yield	Encapsulation efficiency (%)	Swell size (µm)	Muco-adhesion (%)	Bio-adhesive strength (g)	Density (g/mL)	Stabilized chemically/ heat treatment
ALP-1	37.13 ± 1.15	69.50	76.31 ± 1.64	42.63 ± 1.27	85 ± 1.27	8.03	1.22	Glutaraldehyde
ALP-2	31.48 ± .89	73.42	79.21 ± 1.05	32.53 ± 1.37	79 ± 1.29	8.36	1.31	At 125ºC, 15 mins.
ALP-3	24.93 ± 1.73	78.76	80.51 ± 1.13	24.03 ± 0.57	86 ± 1.45	7.98	1.43	At 125ºC, 30 mins.
ALP-4	23.85 ± 2.02	80.50	82.91 ± 1.18	21.93 ± 1.07	83 ± 1.27	8.79	1.56	At 125ºC, 45 mins.
ALP-5	22.85 ± 1.29	82.10	83.91 ± 1.15	18.53 ± 1.56	80 ± .29	9.12	1.59	At 125ºC, 60 mins.

In all the formulations D/P ratio of 1 : 3, agitation speed of 1000 rpm was kept constant,

*Data are expressed as mean ± SD, n = 3

Table 2: Influences of polymer to drug ratio on % yield, %drug entrapement effiency, particle size, degree of swelling, and mucoadhesion

Formulation code	Drug to polymer ratio	% Yield	% Drug entrapment efficiency	Particle size (µm)	Degree of swelling	% Muco-adhesion
ALP-6	1 : 2	63.56	65.18 ± 1.18	15.56 ± 1.86	0.832 ± 0.0412	79 ± 1.31
ALP-7	1 : 3	78.76	80.51 ± 1.13	24.93 ± 1.73	0.932 ± 0.0412	86 ± 1.45
ALP-8	1 : 4	80.20	80.21 ± 1.15	25.53 ± 1.57	1.032 ± 0.0412	87 ± 1.24
ALP-9	1 : 5	84.20	79.25 ± 1.12	35.28 ± 1.17	1.142 ± 0.0412	88 ± 1.35

In all the formulations, agitation speed of 1000 rpm, and temperature of 125°C was kept constant

*Data are expressed as mean ± SD, n = 3

Table 3: Effect of volume of processing medium, temperature, agitation, speed on particle size of microspheres

Formulation code	Vol. of processing medium	Temp. (°C)	Agitation speed (rpm)	Particle size (µm)
ALP-10	100 mL	125	1000	24.93 ± 1.73
ALP-11	100 mL	135	1000	22.63 ± 1.25
ALP-12	100 mL	145	1000	19.03 ± 1.45
ALP-13	100 mL	155	1000	14.93 ± 1.17
ALP-14	100 mL	125	1100	19.93 ± 1.67
ALP-15	100 mL	125	1200	14.94 ± 1.77
ALP-16	100 mL	125	0900	30.43 ± 1.37
ALP-17	100 mL	125	0800	35.93 ± 1.17
ALP-18	150 mL	125	1000	20.73 ± 1.17
ALP-19	200 mL	125	1000	16.73 ± 1.20

In vitro drug diffusion studies

The experimental conditions of drug release experiments were similar to those encountered in the nasal cavity. The *in vitro* drug release of the microspheres was carried out using Frenz diffusion cell[31,32]. This apparatus was designed to imitate the nasal cavity and it comprises a donor and receptor compartments. Fresh goat nasal mucosa was collected from a nearby slaughter house. The nasal mucosa of goat was separated from sub layer bony tissues and stored in distilled water containing few drops of Gentamycin injection (with three openings each for sampling, thermometer and donor tube chamber). The receptor compartment with capacity of 60 mL was used in the study in which phosphate buffer pH 6.8 was taken. Within 80 min of removal, the nasal mucosa measuring an area of 3 cm was carefully cut with a scalpel and tied to the donor tube chamber and it was placed in contact with the diffusion medium in the recipient chamber. Microspheres equivalent to 5 mg of PG were spread on the goat nasal mucosa. At hourly intervals, 1 mL of the diffusion sample was withdrawn with the help of a hypodermic syringe, diluted to 10 mL and absorbance was read at 241 nm. Each time, the sample withdrawn was replaced with 1 mL of pre-warmed phosphate buffer (pH 6.8) to maintain a constant volume of the receptor compartment vehicle.

In vitro drug release kinetics

For understanding the mechanism of drug release and release rate kinetics of the drug from the dosage form, the data obtained was analyzed with software (Kinet DS 3 rev. 2010)[33] equipped with zero order, first order, Higuchi matrix, Hixon-Crowell and Krosmeyer-Peppas, Weibull model kinetics.

Stability studies

The selected formulations were packed in amber colored glass containers and closed with air tight closures and stored for 90 days at 37ºC ± 2ºC. Samples were analyzed at the end of 30, 60 and 90 days and they were evaluated for % Drug entrapment efficiency, *in vitro* mucoadhesion test and *in vitro* drug diffusion studies.

Melting point

A small amount of the microspheres was taken and they were ground to remove the coating material and then subjected to melting point determination.

RESULTS AND DISCUSSION

Preparation of microspheres

Egg albumin microspheres of progesterone were prepared by simple multiple emulsion technique and heat denaturizing process. The microspheres obtained under these conditions were spherical, free flowing and without aggregation in the size range of 15-37 μm, which are therefore suitable for nasal administration. Each step of microspheres was keenly observed to understand the effect on particle size, total entrapment and release profiles of the drug loaded microspheres. In multiple emulsion systems involving aqueous albumin droplets in vegetable oils, the droplets may be relatively stable without the use of any stabilizer. Albumin molecules contain many hydrophobic residues. When aqueous albumin droplets comes in contact with a hydrophobic environment such as a vegetable oil, the polypeptide chains at the interface adopt conformations in which the hydrophobic side chains are positioned toward the surface of the droplets. This conformational change by the protein molecules leads to the formation of a hydrophobic layer around the droplets, and thus stabilizes the emulsion system. The initially formed albumin droplets to the corresponding particles are result of the gradual hardening of the droplets by covalent crosslinking. This crosslinking process can be accomplished either thermally or by the addition of a chemical crosslinking agent.

SEM analysis

Surface morphology was studied using scanning electron microscopy (SEM). Placebo microspheres exhibited the smooth surface while the incorporation of drug imparted a slight roughness to the surface. Optimized process and formulation parameters resulted in spherical shape and rigid surface (Figs. 1 and 2).

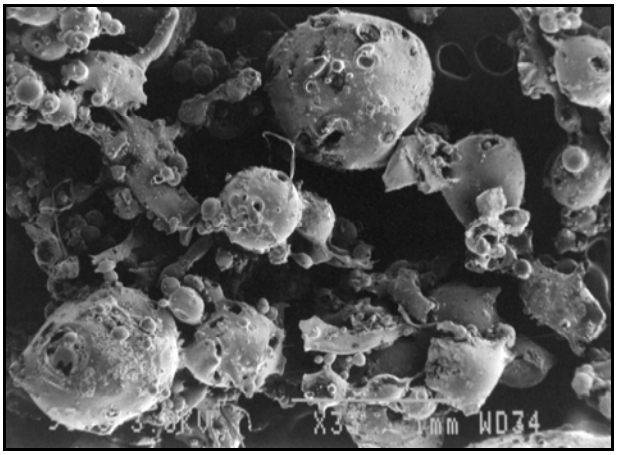

Fig. 1: Placebo albumin microspheres

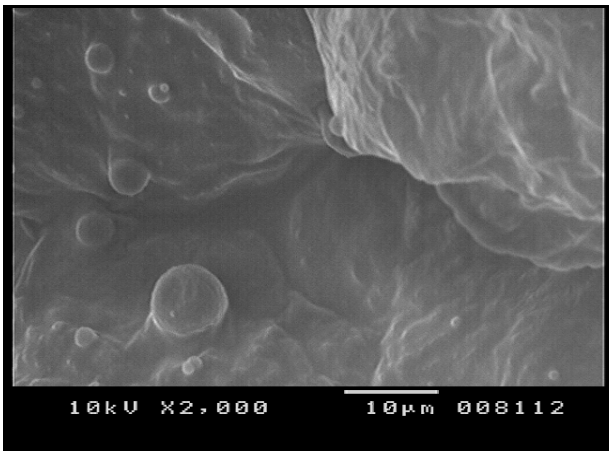

Fig. 2: Progesterone albumin microspheres

IR Spectroscopy

The IR spectra of the free drug and the microspheres were recorded. The drug-excipients compatibility studies reveals that there is no physical changes observed in the

drug and polymer mixtures. The IR spectrum of the drug, drug-albumin mixture and microspheres formulation were compared to find any change in the frequency of functional group in microspheres with respective functional group of the drug.

The spectral observations indicated that the principle IR absorption peaks observed in the spectra of the drug were close to those in the spectra of the microspheres indicates that there is no interaction between the drug and the polymer. The identical peaks corresponding to the functional groups and features confirm that neither the polymer nor the method of preparation has affected the drug stability (Figs. 3-6).

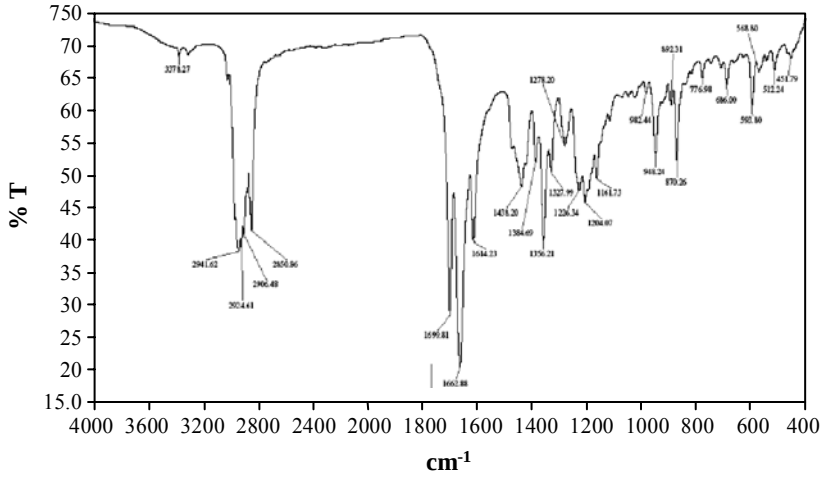

Fig. 3: P-1 Progesterone

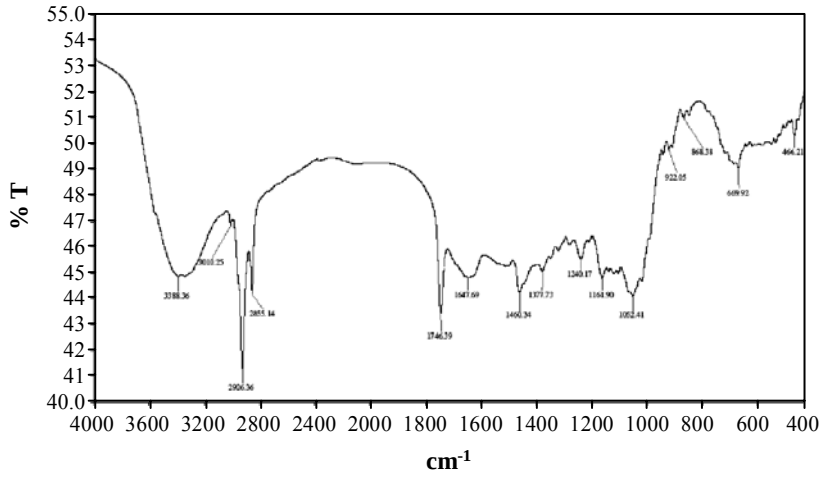

Fig. 4: A-2 Placebo albumin microspheres

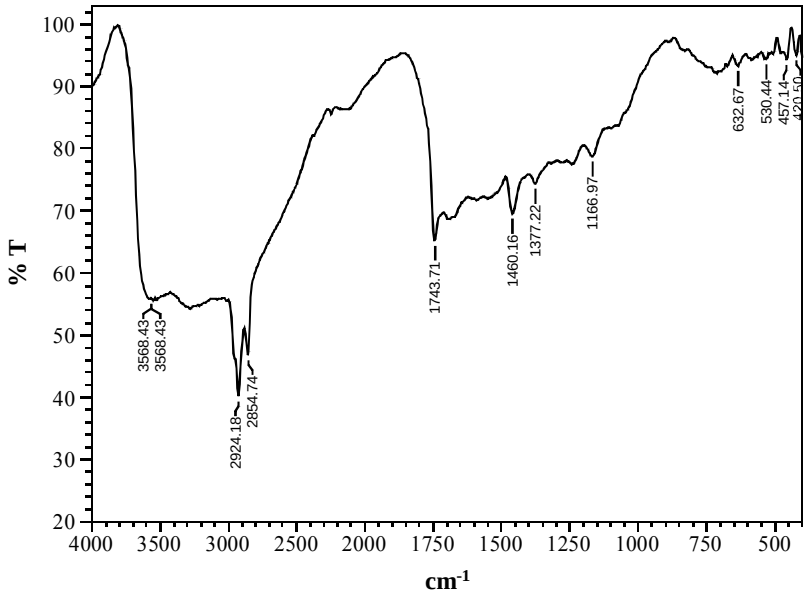

Fig. 5: PA-2-loaded progesterone albumin microspheres

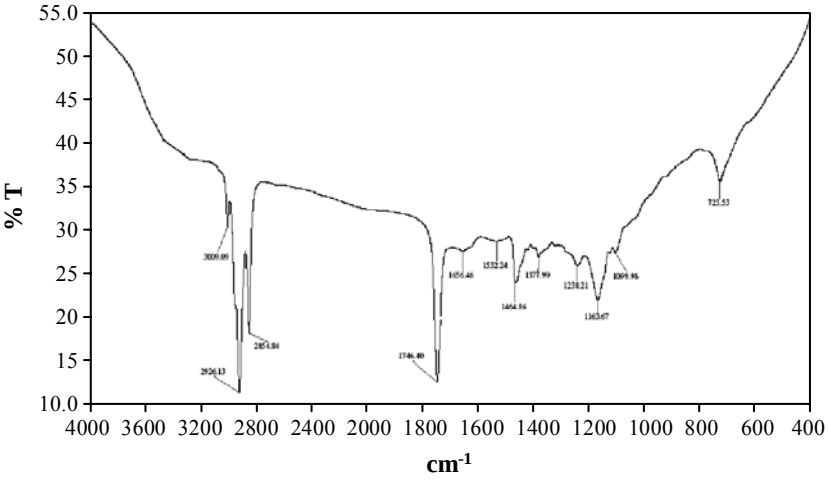

Fig. 6: P + A - 2 physical admixture (N + A)

Melting point

The melting points of the free drug and the drug in the microspheres were found to be the same 131^{o}C indicating that there is no change in the nature of the entrapped drug due to the process of formulation of the microsphere.

Stability studies

It was observed that there was no significant change in the drug content of the microspheres which were stored at 37ºC ± 2ºC at the end of 30, 60 and 90 days. The extent of mucoadhesion of the formulations did not show any significant change after the microspheres were subjected to stability studies. *In vitro* drug diffusion studies for all the four formulations were carried out at the end of 90 days and did not reveal any significant change in drug release from all the formulations. Thus, it can be conclude that the drug does not undergo degradation on storage

Mucoadhesion

Percentage mucoadhesion was found in the range from 79% to 88%. Bioadhesive strength was in range from 8.03 g to 9.12 g. The effect of heat treatment did not affect bioadhesion significantly. Thus progesterone microspheres prepared were found to have good mucoadhesive property.

Effect of experimental variables on particle size distribution

It was observed that with increase in egg albumin concentration in the microspheres from batch ALP-6 to ALP-9 (Table 2) the particle size of microspheres increased, which may be due to the fact that increase in the concentration of polymer increases the cross linking, and hence the matrix density of the microspheres increased, and that may result in the increase in the particle size of the microspheres. The increase in the particle size observed with increase in polymer and drug concentration was due to increase in viscosity of the droplet which resulted in the formation of large droplets, thus increasing the particle size of microspheres.

Increase in the temperature from 125ºC to 145ºC led to decrease in the mean particle size Increase in temperature from 125ºC to 145ºC increases the degree of congealing or rigidization of the polymer, which ultimately results in shrinking of the particles, leading to a decrease in particle size. Hence for the final formulation design a temperature of 125ºC was optimized.

The results were in general agreement with the general theory of microspheres that the particle size of microspheres prepared at 1200 rpm were smaller than those prepared at 800, 900 and 1000 rpm. Since the microspheres obtained at 1000 rpm were in the size range of 15-37 μm suitable for nasal delivery, 1000 rpm was chosen to obtain microspheres. When

the stirring speed was decreased from 1000 to 800 rpm, the mean particle size of the microspheres was increased and they were large and aggregated. When the speed was increased from 1000, 1100 to, 1200, rpm, the size of the microspheres was decreased in the size range.

When the volume of the processing medium was increased from 100 mL, 150 mL and to 200 mL, mean particle size of microspheres were decreased (Table 3), because when the volume of processing medium was increased, the emulsion droplets can be moved freely in the medium and they had less chance to collide with each other there by yielding small and uniform microspheres. Conversely, when the volume is only 100 mL, the emulsion droplets had more opportunities to collide with each other and fuse together to form larger microspheres.

Yield and entrapment efficiency

The microspheres were analyzed for the drug content uniformity and the encapsulation efficiency. The yield and entrapment efficiency of drug loaded microspheres of different polymer to-drug ratios are shown in (Tables 1 and 2). Progesterone was found to be encapsulated 65-83% which shows that if there is an increase in the concentration of the polymer, the encapsulation efficiency also increases. Encapsulation efficiency of the drug was dependent on its solubility in the solvents and processing medium and also depends on the physicochemical properties of the drug and polymer. The higher entrapment efficiency than expected may be attributed to the lower affinity of the oily inner phase of the o/w/o emulsion towards the external emulsion phase and to consequently higher stability of the double emulsion which inhibit drug migration. The decrease in entrapment efficiency with increase in drug concentration could be related to the increased extent of drug diffusion to the external phase due to greater flux at higher drug content during the emulsification and microsphere formation process.

Swellability

Swellability is an indicative parameter for rapid availability of drug solution for diffusion with greater flux swellability. Equilibrium swelling degree increases as the concentration of polymer increases while it decreases as concentration of drug increases as compared to plain microspheres. In general, the higher the extent of crosslinking, the lower the swellability(hydration), and the lower the rate of particle biodegradation/drug release. The density of microspheres stabilized at 125ºC for 60 min was maximum whilst those stabilized for 125ºC for 15 min possessed minimum density (Table 1). However, the swollen

volume was remarkably different and was noted to be minimum in the case of microspheres treated at 125°C for 60 mm. Swellability could be attributed to the tortuosity of the microspheres whilst the latter could be accounted for by the degree of cross-linking or magnitude of denaturation that results in reorientation of albumin macromolecules. It can be concluded that incorporation of drug in microspheres decrease ESD.

Kinetic analysis of release

PG microspheres obtained by thermal crosslinking show higher drug content with respect to those obtained by chemical crosslinking. Thermal crosslinking probably reduces the time interval in which the drug can diffuse from the oily inner phase through the albumin aqueous solution due to its more rapid establishment compared with chemical crosslinking where the crosslinking agent has to diffuse from the external oily phase towards the aqueous albumin phase to start crosslinking. The differences observed between the different crosslinkers are probably due to their different partition rates between these two phases.

Microspheres (ALP-1-ALP-9) prepared at heat stabilization temperature of 125^{o}C were studied for drug release rate. Measurable change in release rate was found. Release experiments with heat and chemically stabilized microspheres showed that with increasing density of microspheres due to heat treatment for varied time the release rate decreased. This is probably due to the closer trapping of solute molecules in the denatured albumin structure of high tortuosity. The decrease in release of drug from microspheres stabilized at 125ºC for 60 min was significant as compared to those which had not been heat-denatured but chemically stabilized. Heat stabilization temperature of 125^{o}C was chosen on the basis of optimum drug release from microspheres. Slower drop rate of 20 ± 10 drops per minute also caused charring of microspheres due to prolonged heating.

The *in vitro* diffusion of PG from the prepared microspheres exhibited the extent of drug release decreased from 90-66% (Figs. 7 and 8). A significant decrease in the rate and extent of drug release is attributed to the increase in density of polymer matrix that results in increased diffusion path length which the drug molecules have to traverse. The release of the drug has been controlled by swelling control release mechanism. No initial burst release has been recorded except for PG microspheres stabilized using 25% w/v glutarldehyde as cross-linking agent. These findings are suggestive of effective washing of surfacial drug of microspheres after their stabilization. Additionally the larger particle size at higher polymer concentration also restricts the total surface area thus resulting in slower drug release over a span of 8 hr.

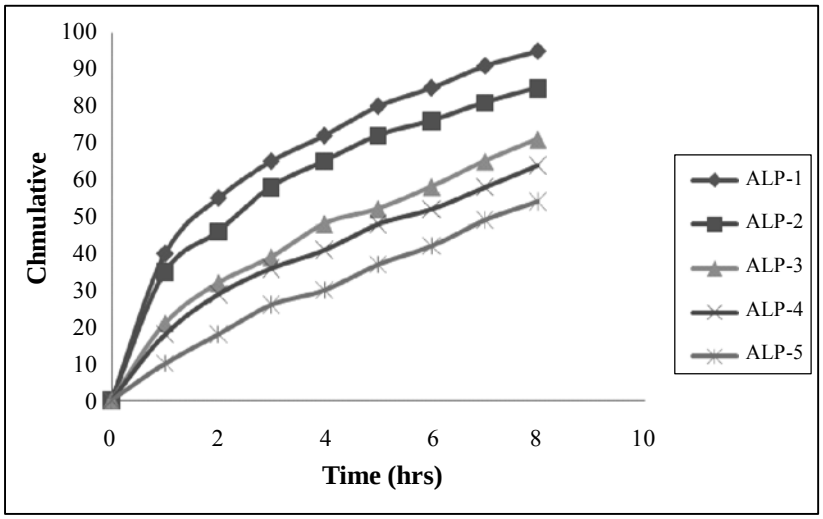

Fig. 7: *In vitro* diffusion profile of PG microspheres

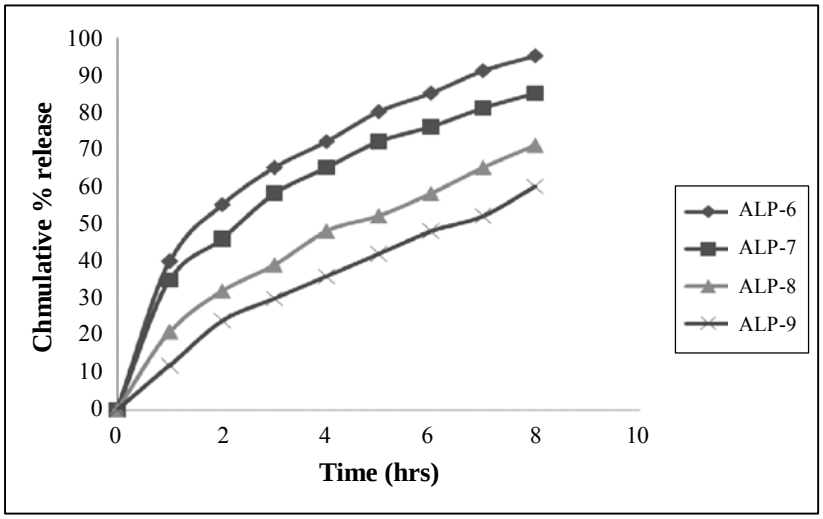

Fig. 8: *In vitro* diffusion profile of PG microspheres

The release models with foremost applications and best describe release phenomena are zero order, first order, Higuchi matrix, Hixon-Crowell and Krosmeyer-Peppas model. The best model would be the one with highest adjusted coefficient determination (R^2). The Akaike Information Criterion (AIC) has become standard tool in model fitting and its computation and is available in many statistical programs. When comparing several models for given set of data, the model associated with the smallest value of AIC is regarded as

giving the best fit out of that set of models[34-35]. The release data obtained were evaluated kinetically using (Kinet DS 3 rev 2010) software[33]. The zero order, Higuchi matrix, Hixon-Crowell, Krosmeyer-Peppas model were found to be suitable. By analyzing the R^2 and AIC values, the best fit model was arrived at Krosmeyer-Pappas model (Tables 4 and 5). The data obtained were also put in Krosmeyer-Peppas equation in order to find out n values, which describes the release mechanism. The observed diffusion coefficient n value was between 0.5188-0.8977 indicating that the mechanism of the drug release was diffusion controlled and follows non-Fickian transport mechanism.

Table 4: *In vitro* release data fitting into various mathematical models

Kinetic Model	Constant	Formulation code				
		ALP-1	**ALP-2**	**ALP-3**	**ALP-4**	**ALP-5**
Zero order	R^2	0.9622	0.9572	0.9877	0.9857	0.9948
	K	7.5357	6.9761	6.8571	6.2142	6.1666
	AIC	4.0331	4.012	2.9635	2.9280	2.0962
First order	R^2	0.8997	0.8972	0.9212	0.9085	0.9098
	K	1.1289	1.1849	1.5882	1.6197	2.1976
	AIC	4.8132	4.7972	4.4265	4.3412	4.4895
Higuchi	R^2	0.9464	0.9658	0.9762	.09724	0.8333
	K	3.6299	3.2140	2.3311	2.8380	1.5217
	AIC	4.3117	3.8332	3.4904	3.4536	4.8715
Hixon-Crowell	R^2	0.9238	0.9200	0.9507	0.9425	0.9519
	K	1.5182	1.5277	1.8381	1.8006	2.1828
	AIC	4.5542	4.5354	3.9690	3.8868	3.7859
Peppas	R^2	0.9983	0.9960	0.9978	0.9967	0.9977
	K	4.0675	3.5043	2.1088	1.8474	1.0204
	n	0.5188	0.6589	0.7657	0.8654	0.8977
	AIC	1.5600	2.2531	1.9132	1.7839	1.514

Table 5: *In vitro* release data fitting into various mathematical models

Kinetic Model	Constant	Formulation code			
		ALP-6	**ALP-7**	**ALP-8**	**ALP-9**
Zero order	R^2	0.9603	0.9541	0.9887	0.9864
	K	7.5404	6.9369	6.8547	6.2059
	AIC	4.073	4.0618	2.8941	2.8828
First order	R^2	0.8942	0.8934	0.9224	0.9103
	K	1.1341	1.1840	1.5944	1.6214
	AIC	4.8354	4.8245	4.3895	4.3390
Higuchi	R^2	0.9476	0.9639	0.9745	0.9727
	K	3.622	3.2033	2.3180	2.0782
	AIC	4.2957	3.8685	3.5437	3.4398
Hixon-Crowell	R^2	0.9197	0.9164	0.9521	0.9438
	K	1.5229	1.5240	1.8424	1.8012
	AIC	4.5802	4.5681	3.9221	3.8786
Peppas	R^2	0.9973	0.9952	0.9975	0.9974
	K	4.0429	3.4906	2.0919	1.8419
	n	0.6543	0.7656	0.8025	0.8132
	AIC	1.8210	2.4285	1.9855	1.5183

CONCLUSION

The multiple emulsification technique for obtaining microspheres has proved to be a useful tool in the preparation of microspheres for nasal drug delivery. By virtue of prolonged drug residence at the site of absorption, improved bioavailability can be achieved.

Drug- polymer ratio, stirring speed and dispersing medium influenced the sphericity of the microspheres. The entrapments efficiency, production yield, was high for all the formulations. It was suggested that mechanism of drug release from microspheres was diffusion and erosion controlled.

All the microspheres were at a suitable size and had good mucoadhesive property for nasal administration. The hydrophilic polymer egg albumin and the microsphere system

achieved to modify the *in vitro* release of PG. The stability data showed that there was no change in the appearance of the microspheres indicating that the formulations were stable at different conditions of storage.

Absorption of the natural progesterone is highly variable due to stomach content and strong first-pass metabolism. It may be advantageous to administer progesterone by nasal route. The result from the present study indicates that it is possible to achieve enhanced bioavailability of progesterone by using egg albumin microspheres. The data obtained in this study suggest that thermal cross-linked egg albumin microspheres would be promising biodegradable carrier for long delivery of steroids. It is concluded that PG could be successfully steered via the nasal route Moreover, controlled drug release following nasal administration of bioadhesive egg albumin microspheres resulted in sustained and controlled drug absorption.

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