International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

Overview on Liposomal Pulmonary Drug Delivery to Lung

Swati D. Raysing[1], Kumesh B. Basene[2]

[1,2]*Department of Quality Assurance, R. C. Patel Institute of Pharmaceutical Education & Research, Near Karwand naka, Shirpur 425405, Dist. Dhule, M.S; India*

***Abstract*— This review focused on liposomal pulmonary drug delivery which provides active and passive targeting to treatment of lungs disease. Targeting via pulmonary route it provides 2nd highest surface area. There are different kinds of cells which are lined throughout airways epithelium to alveoli having specific functions. Physiological obstacles in the lungs and airways which having role for defensive and protective functions. Liposomes are considered highly suitable carriers for pulmonary drug delivery because their phospholipid composition resembles pulmonary surfactant, enabling biocompatible, targeted, and sustained drug delivery within the lung environment. Liposomes can be administered via pressurized metered-dose inhalers (PMDIs), dry powder inhalers (DPIs), and aerosol systems, which enhance formulation stability according to requirements and provide convenient, patient-friendly delivery. There are different methods for the preparation of liposomes, each offering specific advantages based on formulation requirements. Multilamellar and reverse-phase evaporation methods provide high drug entrapment and controlled vesicle formation. Freeze-drying improves stability and shelf life, while proliposome techniques enhance ease of storage and reconstitution. These methods enable efficient and adaptable liposome formulations for pulmonary drug delivery.**

***Keywords*—Alcohol-Based Proliposomes, Dry-Powder Inhalers, Freeze-Dried Liposomes, Liposomes, Multilamellar Evaporation, Nebulizers, Particulate-Based Proliposomes, Pressurized Metered-Dose Inhalers (PMDIs), Reverse-Phase Evaporation.**

I. INTRODUCTION

A. Anatomy of lung

The lungs are mainly consists of branched airways and billions of alveoli at the ends. Alveoli are plays important role that why they called as Basic functional units of the lungs. In addition to performing crucial role involving structural maintenance and defence tasks, their primary responsibility is to achieve effective gas exchange More significantly, the lungs perform crucial non-respiratory tasks in addition to their primary respiratory role, such as filtering small emboli in the blood and protecting against inhaled infections and particulate matter via the mucociliary system and immune cells [1].

The lungs have an efficient and precise structure. With hundreds of millions of thin-walled alveoli joined at the ends to form a massive gas exchange interface, the interior branches form a complex network of bronchial trees [2]. Through the trachea, air enters the left and right major bronchi. From there, it gradually branches into the lobar bronchi, segmental bronchi, tiny bronchi, thin bronchi, and terminal thin bronchi before entering the respiratory thin bronchi, alveolar ducts, and alveolar sacs. The alveoli, which are made up of dispersed type II alveolar epithelial cells and incredibly thin type I alveolar epithelial cells, are the fundamental units of gas exchange. Their walls create a vast surface area for gas exchange because they are closely connected to a dense network of capillaries. The airways of lungs luminal surface is consists of the continuous cells sheet lining to forms epithelium.

It divides the body's internal environment (subepithelial structures) from its external environment (airway lumen). As a result, the epithelium's lumenal surface is exposed to gases, particles, and aerosols that are breathed.

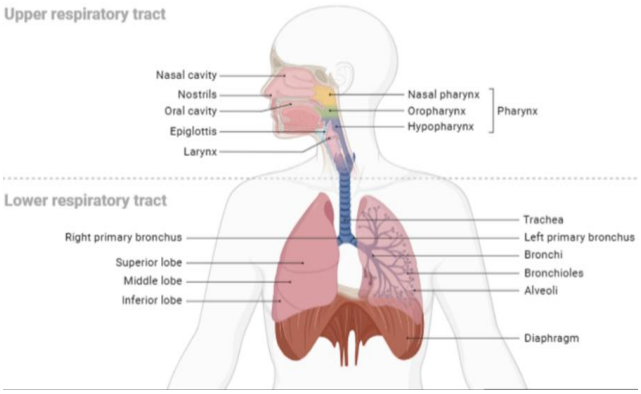

Figure I. Illustration of upper and lower Airways [3]

B. Description of Airways and Lung Structure

The respiratory system was started from the nasopharynx and oropharynx, then travelled through the bronchial and tracheal regions and ends at the last alveoli. The main function of the respiratory system was to be the exchange and transportation of the gases. Lung are the primary organ throughout the respiratory system.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

Lungs are consists of two organs which are located side of each, which both the organ are similar to each other but the left lung is smaller and narrower than the right lung. While talking about right lung its consists of three lobes and separated by two oblique fissure. The helium is the anatomical part of the lung which plays role as to connect the two lungs to trachea and heart [4].

There are several different cell types in the airway epithelium (Table 1), This gives the area of the airways distinct functions. The lumenal surface of the airways are lined by ciliated cells from the trachea to the terminal bronchus. Mucus, a viscous fluid containing mucin glycoproteins and proteoglycans, floats on a watery layer of periciliary fluid (or sol) and covers the lumenal surface of the epithelium There are four key roles that the secretions play. It keeps the epithelium from drying out, to start with. Second, the water in the mucus encourages inhaled air to become saturated. Thirdly, defensins and lysozyme, two antibacterial proteins and peptides found in mucus, prevent microorganisms from colonizing the airways [5][6].

Compared to other entrance points into the body, the lung offers significantly higher bioavailability for macromolecules [7][8]. Human growth hormone and other large proteins (18–20 kDa) have pulmonary bioavailability that approaches or surpasses 50% [9], although insulin and tiny peptides may have bioavailability that approaches 100%.

TABLE I
CELLS OF THE EPITHELIUM OF THE AIRWAYS [12]

Cells	Proposed Function
Ciliated columnar	Movement of Mucus
Mucous (goblet)	Secretion of mucus
Serous	Mucus fluid; Periciliary fluid
Clara (nonciliated epithelial)	Surfactant production; xenobiotic metabolism
Brush	Ciliated epithelial cells in a transitional state
Basal	Progenitor for ciliated epithelial and goblet cells
Dendritic	Immunity
Intermediate	Transitional cell in differentiation of basal cell
Neuroendocrine (Kultschitsky or APUD)	Chemoreceptor; paracrine function
Alveolar type I	Alveolar gas exchange
Alveolar type II	Surfactant secretion; differentiation into type I cell
Alveolar macrophage	Pulmonary defense
Mast	Immunoregulation

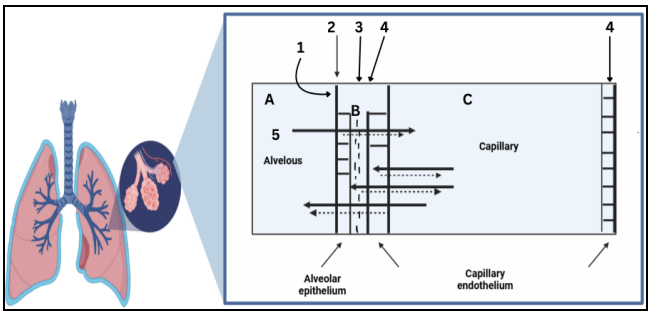

Figure II. Diagrammatic illustration of the respiratory membrane's ultrastructure [12]. Arrows show how drugs (horizontal heavy lines) or metabolites (horizontal broken lines) produced in the epithelial or endothelial layers travel through the respiratory membrane following exposure to alveoli or capillaries Key: (1) layers of monomolecular surfactant; (2) thin fluid film; (3) interstitial space; (4) endothelial capillary basement membrane; (5) drug transport from the alveoli; (6) drug absorption into endothelial cells from the circulation; (7) drug transport from the circulation to alveolar epithelium; and (8) drug transport from the circulation to the alveoli.

In recent years, there has been an increased focus on the absorption of pharmacological compounds through the lung epithelium. The layer of epithelial cells lining the lung abruptly transitions from the ciliated columnar cells of the constricting airways to the flattened cells of the alveolar region.

According to earlier research by [10] and [11], the majority of xenobiotics are absorbed by passive diffusion at rates that match their apparent partition coefficients at pH 7.4. Therefore, the endothelial membrane seems to behave like a conventional phospholipid membrane, similar to the gastrointestinal membrane. Nonetheless, poorly lipid-soluble substances typically travel faster than one might anticipate, indicating that water holes may facilitate pulmonary epithelium diffusion. Furthermore, it is known that some medications (such disodium cromoglycate) exhibit carrier-mediated transport, which is exclusive to lung epithelial cells. improvement of medication absorption through modified vesicular (transcellular) or junctional (paracellular) transport. The pulmonary absorption of peptides and proteins < 40 kDa can be explained by the paracellular transport process.

Paracellular channels between epithelial cells have a pore radius of roughly 1 nm, which is 25% of the pore radius between neighbouring endothelial cells. Therefore, macromolecules (like horseradish peroxidase, MW 40,000; molecular radius >3 nm) having molecular radii larger than 2 nm are totally prohibited from paracellular transport. This suggests that either endocytosis by the epithelium or phagocytosis and subsequent epithelial penetration are the primary mechanisms of big particle transport across normal pulmonary epithelium [12].

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

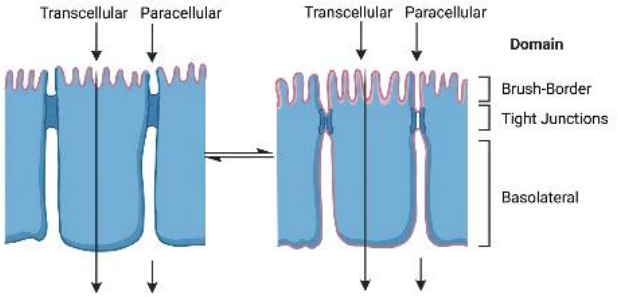

Figure III. Transport routes between lung epithelial cells that are both transcellular and paracellular [12].

II. Physiological Obstacles Found In The Lungs And Airways

The mechanism of lung clearance of the xenobiotics are involved two kinds of primary mechanism by Mucus-cilia clearance and macrophage phagocytosis [13]. Mucus -cilia is the main defence mechanism of the airways which are works for the involving role for eliminating the particles whose diameter are larger than five micrometres. When tiny particles are entered in the alveolar region are get eliminated by the phagocytosis by the alveolar macrophages (AM), phagocytosis its immunological defence mechanism or biological response in the lungs. Phagocytosis by the AM its depends on the particle size of the foreign material enters inside, optimal particle size for macrophage phagocytosis is 1.5–3 µm, while particles larger than 5 µm have poor phagocytosis [13][14].

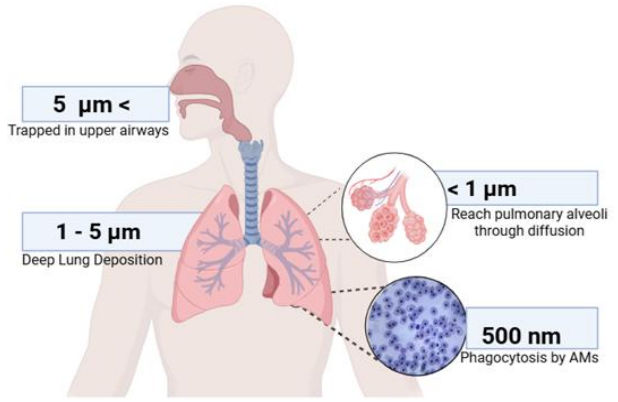

Figure IV. Diagrammatic Illustration of role of particle size on lung deposition & Phagocytosis by alveolar macrophages [15].

Drug targeting with parenterally delivered liposomes has proven to be a challenging objective [16]. That why there is recently focused for alternative to the parenteral route of administration like topical liposome administration involving pulmonary route also another one is targeted cell drug delivery, tissue- selective Numerous recent studies have examined advancements in pulmonary liposome medication delivery [17–18].

By inhaling medication aerosols, topical therapy is especially accessible to the sick lung [19, 20]. Aerosolized antimicrobials, such as aminoglycosides and ribavirin for respiratory syncytial virus infections [21], pentamidine for the treatment of infants [22], and pulmonary Pneumocystis carinii infections in immunocompromised patients [23], have only recently been introduced, despite the widespread use of antiasthmatic agents administered via metered and antiallergic dose inhalers (MDIs).

The difficulties which are associated with the for liposomes when given by an pulmonary route: (i) patients must need to be trained to coordinate aerosol inhalation and breathings; (ii) Some drug are having poor aqueous solubility, they cause local irritation and inflammation in the airways or may lead to prevent use of aerosol entirely; (iii) Poor cytosolic penetration drugs to treat intracellular pathogens. Rapid lung absorption of most medications, such as bronchodilators and corticosteroids, necessitates frequent dosage, which is another therapeutically unfavourable feature of pulmonary drug delivery; (iv) While some drugs are get quickly absorbed, they need to frequent administration, may may result in systemic side effect due to increase in the concertation in the blood [24].

Table II.
Inhaled liposome aerosol clearance and anatomical/ functional deposition patterns [24]

Anatomical structures	Mechanism of deposition	Dro-plet size (µm)	Factors that affect	Mechanism for clearance
Naso/ oropharynx	inertial impaction	<100	anatomic obstruction secretions edema	Swallowing expectoration mucociliary
Tracheobronchial	inertial impaction sedimentation Diffusion	<40	Bronchospasm anatomic obstruction mucus hyper-secretion respiratory pattern (depth/rate)	Cough Mucociliary bronchial lymphatics via macrophages
Pulmonary (alveolar)	Sedimentation diffusion	<5	respiratory pattern fibrosis atelectasis	Endocytosis surfactant incorporation lymphatics via macrophages

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

Liposomes are do the overcomes the problem which are associated with the traditional aerosol distribution because liposomes are contributes by:

(i) They can serve as carriers that improve the solubility of drugs with poor aqueous solubility; (ii) Act as reservoirs that enable prolonged drug release within the lungs, and enhance intracellular drug delivery which may help reduce damage to alveolar tissues.; (iii) Prolonged retention of liposomes in the lungs may also contribute to reduced local drug concentrations at the tissue surface, thereby minimizing irritation or toxicity. At the same time, they can facilitate higher drug accumulation within specific cells, such as infected alveolar macrophages. Overall, these combined effects can improve therapeutic effectiveness while limiting unwanted systemic distribution of the drug [25].

Antimicrobials (enviroxime [27, 28], amikacin [29], pentamidine [30], and glutathione [31, 32]) and anticancer medications (cytarabine [24, 25]) have been studied for pulmonary delivery using liposomes. Pulmonary administration of immunomodulators (MDP [33] MTP-PE]), immunosuppressive drugs (cyclosporin), antiviral drugs (ribavirin), and antimycobacterial drugs (N-acylpyrazinamides [34]) are promising advances.

III. Aerosol's Physical Attributes

The size distribution of the individual droplets influences aerosol deposition, which can be arbitrarily classified as "polydisperse" (less uniform size distribution and op equal to or more than 1.2) or "monodisperse" (uniform size distribution and geometric standard deviation (range) of less than 1.2) [35]. Additionally, the form of the particle (spheres, elongated libers) has a significant impact on how it deposits in the respiratory tract [19]. In essence, liposomes are spherical, polydisperse, insoluble particles. The depth of deposition in the respiratory tract is mostly determined by the size of the aerosol droplet, not the size of the liposome, as will be covered later. The deposition of an aerosol is also controlled by the electrostatic hygroscopicity potential and physicochemical parameters of the aerosolized particles. Because liposomes, particularly unilamellar and oligolamellar vesicles, are osmotically sensitive and frequently designed to carry a negative or positive surface charge, these aspects are especially important for liposome aerosols. Therefore, the deposition and retention of encapsulated (water-soluble) drugs may be significantly impacted by water loss and electrostatic interactions resulting from solvent evaporation or fluxes in the humidity of the environment (see also under Physical characterization of liposome aerosols below) [24].

IV. Function And Anatomy Of The Respiratory Tract

The respiratory architecture of air-breathing animals has evolved to actively prevent inhalation of potential airborne particles. The respiratory tract is a stepwise filtration mechanism in which the nasopharyngeal/oropharyngeal area, tracheobronchial airways, and the pulmonary parenchyma are involved (see Table 2). The deposition of particles in these areas is primarily a matter of size. The larger particles, which are usually above 100 µm, cannot be absorbed by the lower airways and are mostly lodged in the naso-oropharyngeal area. Smaller than 40 µm in diameter particles can be transported further and be deposited in the upper parts of the tracheobronchial tree. Particles that are smaller than about 5 µm in diameter are usually required to reach the alveolar spaces [36].

Not only anatomical structure but also a number of physical mechanisms affect the deposition of aerosol particles in the respiratory tract (see Table 2). Among the most important processes is the inertial impaction; this takes place mainly in the naso/oropharyngeal and upper tracheobronchial airways with the relatively higher airflow velocity. This process is intensified as the breathing rates and the particle size increases. Gradual sedimentation is, on the contrary, significant in the smaller, marginal airways of the tracheobronchial tree, as well as in the pulmonary parenchyma, in which the airflow is slower. Moreover, the submicron-sized particles (extremely fine particles) deposit primarily by diffusion, a mechanism that is caused by the random motion of the particles when suspended in the air. These small particles are able to move deep into the lungs and reach the alveolar region with little hindrance and their deposition may be possible in either inhalation or exhalation [19].

V. Pulmonary Clearance Mechanisms

Lungs have a number of processes which are active in the removal of deposit particles. Primary clearance involves swallowing, coughing, and expectoration processes in the upper parts, including the naso/oropharynx, and the tracheobronchial tree which assist in clearing of any trapped material within the respiratory system. The "mucociliary escalator" (Table 2) is a significant clearance mechanism for inhaled particulate aerosols, including liposomes. It is made up of ciliated epithelial cells that extend from the upper tracheobronchial terminal region and the naso/oropharynx to the most distant bronchioles.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

The coordination between constant beating of the cilia and the secretion of the mucus by the goblet cells, contribute to maintaining an effective clearing mechanism that entraps and eliminates the inhaled particles in the respiratory tract.

Aerosolized radiolabeled liposomes administered to central tracheobronchial areas exhibited temporal clearance patterns compatible with mucociliary escalator activity, according to Farr et al. [37]. In the alveolar region of the lungs, the dominant mechanism for removing deposited particles is their uptake by pulmonary alveolar macrophages, as reported by Forsgren et al. [38] and Myers et al. [39] have now confirmed that endocytic absorption of aerosolized inhale liposomes by pulmonary alveolar macrophages takes place in vivo.

In contrast to many inhaled particles that deposit in the alveolar region, liposomes can be cleared through an additional pathway. They may integrate into the pulmonary surfactant phospholipid pool, where alveolar type II cells process them by digestion, uptake, and subsequent recycling along with endogenous surfactant components [40,41].

VI. Liposomal Pulmonary Delivery Benefits

The pulmonary region offers the second-biggest surface area (100 m2) in the human body [42], with the gastrointestinal tract having the greatest [43]. This is a major benefit of focusing on the pulmonary region for molecular absorption. Furthermore, compared to the nasal tract, the pulmonary region is significantly larger [44]. Compared to other lung surface regions [45] or other non-invasive drug delivery methods, aerosol medicines deposited in the pulmonary region are exposed to a shorter pathway (by 100–600 times) for transportation to the blood arteries. Furthermore, the walls of the upper lung airways and the GI and nasal tracts contain thick mucus linings (5–10 mm) that serve as diffusion barriers by preventing macromolecular transfer to the blood vessels [46,47].

Aerosol particles interact with the lungs' thinner absorptive epithelium as they move deeper into the lungs. Furthermore, cilia and mucus secretion are essentially absent from the pulmonary area. Aerosol drug particles only need to interact with a small monolayer of surfactant molecules dispersed over a surface lining fluid (0.1–0.2 mm thick) at the air–liquid interface after they are deposited in the pulmonary area [46].

The absence of several physiological barriers, such as enzymatic and metabolic processes and an acidic environment, which may break down numerous drug molecules, proteins, and peptides that are intended for extracellular drug delivery, is a second benefit of pulmonary drug delivery over the GI tract. Macrophages are the only physiological barrier in the pulmonary area [48].

These are mobile cellular entities seen on the surfaces of alveoli that have the ability to phagocytose and denature proteins and peptides. Nanometer-sized (5260 nm) or surface-modified particles containing hydrophilic polymers (like polyethylene glycol) are examples of engineered particles that can avoid phagocytosis and make them less vulnerable to macrophage uptake [49, 50].

Apart from these benefits, the pulmonary surface can reduce the needless accumulation of foreign substances like excipients or inert colloidal drug carriers, which are typically utilized in medication compositions. The inert residues of drug formulations are readily removed from the pulmonary surface, either by a natural mechanism or by lung macrophage digestion, with the exception of a few materials that are not biodegradable (such as some polymeric colloidal drug carriers, carbon, and silicon particles) [50, 51].

VII. Liposomes

Definition

Bangham and Horne originally described liposomes, a colloidal drug delivery method, as nanosized spherical vesicles [52]. They are produced spontaneously during phospholipid hydration in aqueous solution and consist of one or more phospholipid bilayers encasing an aqueous compartment [53].

Liposomes can load hydrophilic pharmaceuticals in the aqueous core or lipophilic molecules in the lipid bilayer thanks to the vesicular shape; amphiphilic substances were trapped at the bilayer interface [54,55]. Natural or artificial lipids, which are thought to be comparatively nontoxic and biodegradable materials, make up the majority of liposomes. To change stability or kinetics, additional components like hydrophilic polymer-conjugated lipids and cholesterol may be introduced to the membrane composition [56]. Phospholipid safety has been thoroughly tested for the pulmonary route; inhaling drug-free liposomes [57], fluorescein-labelled liposomes [58], and beclomethasone dipropionate-liposomes [59] in healthy volunteers showed excellent tolerance and no negative side effects. They were shown to be incredibly safe for usage in pharmaceuticals.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

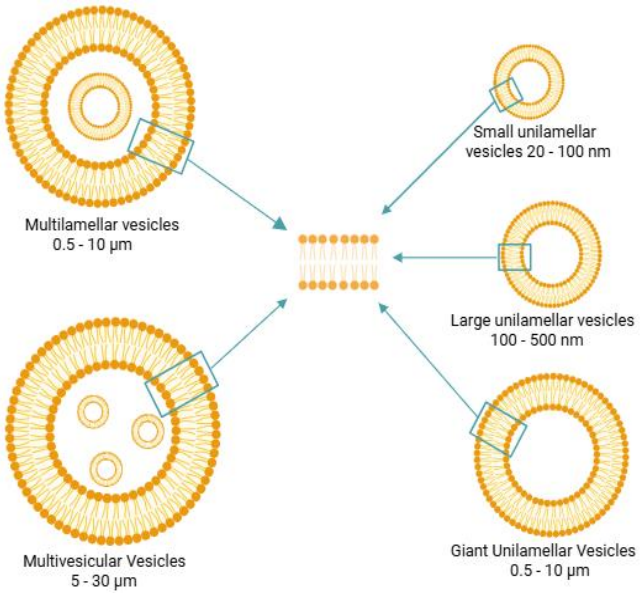

Figure V. Liposomes are categorized based on their size (small, intermediate, or big) and lamellarity (uni-, oligo-, and multilamellar vesicles) [60].

The ability to produce liposomes from phospholipids that are naturally occurring in the lungs as components of lung surfactant is a significant benefit of liposomes as pulmonary medication delivery systems Since the lungs have highly developed systems of transporting and processing foreign materials, vesicular carriers transported to this location are usually predicted to have good biocompatibility [61]. The number of liposome-based formulations tested on human and animal respiratory systems has been wide. These consist of peptide and protein delivery, antioxidants, anticancer, antiasthma, antibacterial, and recombinant genetic material to be used in gene therapy applications [62-71]. The results of these investigations also show that absorption profile of drugs can be modified by encapsulating drugs in liposomes before administration. This alteration tends to provide reduced systemic toxicity, increased retention of the drug in the body and increased localization of therapeutic effect in the lungs.

Liposomes are colloidal carriers, which are likely to exhibit low levels of stability. Physical instability can be manifested as vesicle aggregation or fusion, which results in a change in the size of vesicles, and release of encapsulated hydrophilic drugs.

Moreover, chemical instability may also impair their performance, with the hydrolysis of ester bonds and oxidation of unsaturated lipid chains as examples of processes that may accelerate the breakdown of liposomes in addition to changing the release properties of drugs. Liposomes can be freeze-dried to solve instability issues, but freezing can result in phase-transition changes, osmotic stress, and bilayer expansion from ice formation [73]. These alterations may disrupt the lipid layer, fostering the fusion and aggregation of vesicles. Consequently, the encapsulated contents can leak out [74], and the size distribution of the liposomal population as a whole can be influenced as well [75].

These disruptive influences can be reduced through addition of cryoprotective agents into liposomal preparations like the disaccharides [74]. Moreover, alternative preparation methods have also been discussed in order to improve stability, which can provide other options instead of the traditional freezing methods of drying. There are two forms of proliposomes: particulate-based proliposomes are made up of phospholipid-coated soluble, free-flowing carrier particles [76]. The two kinds of proliposomes can develop liposomes when an adequate aqueous phase is added.

VIII. Liposomal Delivery to the Respiratory Tract

The respiratory system has a complex, branched architecture that functions as a defense mechanism, limiting the accumulation of inhaled substances in the deeper lung regions. The ability of particles to reach the peripheral airways is primarily governed by their aerodynamic diameter. Generally, particles must be smaller than 5–6 µm to access the respiratory bronchioles or alveoli, while those under 2 µm are most suitable for efficient alveolar deposition [77].

Currently, drug administration to the lungs, including liposomal formulations, is mainly achieved using three principal types of inhalation devices.

A. Pressurized Inhalers

Pressurized metered-dose inhalers (PMDIs) deliver drugs in the form of solutions or suspensions dispersed in liquefied propellants. These propellants include traditional chlorofluorocarbons (CFCs) as well as newer, environmentally safer hydrofluoroalkanes (HFAs). When phospholipids dissolved in CFC-based systems come into contact with an aqueous environment such as the respiratory tract, they can spontaneously assemble into vesicular structures [78].

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

In contrast, HFA propellants like HFA-134a are poor solvents for phospholipids [79]. Therefore, newer formulation approaches are likely to involve dispersing pre-formed liposomes—such as freeze-dried or spray-dried vesicles—within the propellant to achieve effective delivery through PMDIs.

B. Dry Powder Inhalers

These systems deliver the drug as a fine powder into the patient's airflow during inhalation. To ensure proper dispersion into respirable particles, formulations often include carrier substances such as lactose, which help in the deaggregation of the drug powder. Such inhalation devices are capable of efficiently aerosolizing liposomes prepared by freeze-drying [80] or spray-drying [81].

Alternatively, proliposome-based strategies have been explored to generate fine liposomal particles. One method involves micronizing a blend of phospholipids, lactose, and the drug [82], while another approach uses spray-drying of an ethanolic solution containing phospholipids and a carrier [83]. The proliposomes produced through these techniques can then be delivered using dry powder inhalers (DPIs).

C. Nebulizers

The third significant type of inhalation device is called nebulizer, which is frequently used in early research in liposomal delivery, because formulations are straightforward to prepare and it can deliver relatively high doses of drug. These include jet nebulizers or air-jet or air-blast nebulizers in which compressed gas is used to change liquid formulations into an aerosol. A very small proportion of the produced droplets is fine enough to be directly inhaled, and the larger droplets are redirected to the reservoir by bouncing against baffles or the sides of the nebulizer chamber.

A jet nebulizer produces an aerosol that comprises of liquid droplets and solvent vapor that moisturizes the air stream exiting the device. As a result, the constant use of it causes a gradual reduction of the temperature of the rest solution and the concentration of the solute to increase with time [83]. It has been demonstrated that the formulation affects how well these nebulizers work for delivering liposomes. When liposomes are subjected to the nebulizer, they can experience structural damage or aggregates disintegration, resulting in significant leakage and loss of the drug carried in [85,86].

IX. METHODOLOGY

Examples of nebulizer that are commonly used [88]

D. Jet Nebulizers

Different commercially available nebulizer models are manufactured by various companies. For instance, the Cirrus device is produced by Intersurgical (Wokingham, Berkshire, UK), while the Hudson model is supplied by Henleys Medical Supplies (UK). The Pari LC, Pari LC Plus, and Pari LC Star nebulizers are developed by Pari GmbH (Germany). Additionally, the Respirgard II system is manufactured by Marquest (USA), and the Sidestream Durable nebulizer is produced by Medic-Aid Ltd (UK). Jet nebulizers were driven by compressible air at a rate that could be adjusted or powered by a Pari Master compressor that was produced by Pari GmbH, Germany.

E. Ultrasonic Nebulizers

Examples are the ultrasonic nebulizer devices along with their models and manufactures as follows: Liberty device is manufactured by Clement Clarke International, U.K. Medix Electronic is produced by Medix Ltd, U.K. and the Omron U11 is a nebulizer produced by Omron Healthcare, U.K.

F. Vibrating-mesh Nebulizers

Examples of vibrating mesh nebulizer devices along with their models and respective manufacturers are given below:

The Aeroneb Pro (large mesh) device is produced by Nektar, U.S.A., while the Omron NE U221 model is manufactured by Omron Healthcare, U.K.

I. METHODS FOR PREPARATION OF LIPOSOMES

G. Reverse-phase and Multilamellar Evaporation

To prepare multilamellar vesicles (MLVs), phospholipids—either alone or combined with equimolar amounts of cholesterol (Chol)-are first dissolved in chloroform within a round-bottom flask. The chloroform was then removed at reduced pressure using a rotary evaporator at 40 °C.

The dried lipid layer is rehydrated by using an aqueous medium at temperatures higher than the phase transition temperature (Tc) of the primary phospholipid, and then mechanical agitation of the mixture is conducted to enhance the development of vesicles.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

In a long-necked, round-bottomed flask, the lipid components were dissolved in chloroform/diethylether (1:1) to create reverse-phase evaporation vesicles (REVs). Subsequently, the aqueous medium is introduced in such a way that the ratio of organic to aqueous phase is maintained at 6:1.

An emulsion was prepared by flushing the flask with nitrogen, sealing it, and subjecting the mixture to sonication for approximately 4–6 minutes at a temperature above the phase transition temperature (Tc). Reverse-phase evaporation vesicles (REVs) were then formed by slowly removing the organic solvent using a rotary evaporator. To achieve a reduction in average vesicle size, the dispersion was passed multiple times, when required, through polycarbonate membrane filters (Nucleopore Inc., U.S.A.) fitted within 25-mm holders.

Various agents such as salbutamol sulfate (albuterol sulphate), sodium cromoglicate (cromolyn sodium), and lactate dehydrogenase (LDH) were encapsulated within the liposomes. Unentrapped drug was separated by either dialysis or ultracentrifugation. The vesicle size and distribution, including volume median diameter (VMD), were subsequently characterized using techniques like photon correlation spectroscopy and laser Fraunhofer diffraction analysis [87].

H. Freeze-Dried Liposomes

Glass-drying jars were filled with liposome dispersions, which were then frozen at 20 °C in a freezer. After that, the containers were placed on an Edwards Micro Modulyo freeze-drier (Edwards Ltd., U.K.) and allowed to dry for twelve hours. Until needed, the freeze-dried samples were kept in dark, vacuum-sealed containers at 1 to 5 °C. Before being used, the freeze-dried liposome samples were fully redispersed by hydrating them with deionized water at room temperature and vortexing them for two minutes [87].

I. Particulate-Based Proliposomes

This method was adapted from Ref. [75]. In this approach, a modified rotary evaporator maintained under reduced pressure at 40 °C was attached to a pear-shaped glass flask containing approximately 300–500 mm sucrose particles. A solution of soy phosphatidylcholine (PC) and cholesterol in chloroform, prepared at a concentration of 60 mg/mL with a 1:1 molar ratio, was gradually introduced into the flask through a feed line. Subsequently, the organic solvent was removed by evaporation under vacuum at the same temperature, leading to the formation of the proliposomal system.

J. Alcohol-Based Proliposomes

The procedure was derived from Ref. [77]. In brief, a proliposomal system containing 50 mg of soy phosphatidylcholine (SoyPC) and cholesterol in a 1:1 molar ratio was first dissolved in 60 mg of ethanol and maintained at 70 °C for about one minute. Subsequently, 100 mL of an isotonic solution (either sodium chloride or sucrose) incorporating 5 mg of salbutamol sulphate was added, and the mixture was stirred gently for one minute. The preparation was then brought to a final volume of 5 mL using the corresponding isotonic medium and shaken vigorously by hand for an additional minute to obtain the final liposomal dispersion.

X. Applications In Disease And Drug

Alveolar diseases include the major killers of emphysema, pulmonary fibrosis, pneumonia, acute respiratory distress syndrome (ARDS), and, more recently, COVID-19 pneumonia.

Drug classes in IDPs containing Liposomes [12]

A. Antibiotics

1. Liposomal Amikacin for Inhalation (LAI, Arikace™, Arikayce)

Amikacin liposome inhalation suspension (ALIS) [Arikayce® Liposomal (EU); Arikayce® (USA)], For individuals with treatment-refractory Mycobacterium avium complex (MAC) lung illness who have few or no other alternatives for treatment, a liposomal suspension of the aminoglycoside amikacin (590 mg) is available for nebulization using the Lamira® Nebulizer System [89].

2. Ciprofloxacin for Inhalation (Lipoquin, Pulmaquin)

For Pseudomonas aeruginosa infections in non-CF bronchiectasis, cystic fibrosis, and nontuberculous mycobacteria (NTM) lung illness, as well as bioterrorism agents including Bacillus anthracis (anthrax) and Yersinia pestis (plague), LipoquinTM (single liposomal ciprofloxacin) was created. Through both immediate and sustained release, PulmaquinTM (dual-release: liposomal + free ciprofloxacin) seeks to reduce Pseudomonas exacerbations in non-CF bronchiectasis [90].

B. Antifungal therapeutics

1. Liposomal Amphotericin B

AmBisome® (L-AmB), also known as liposomal amphotericin B, is an intravenous antifungal formulation used for visceral leishmaniasis and severe invasive fungal infections, especially when traditional amphotericin B is hazardous.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 05, May 2026)

While retaining broad-spectrum effectiveness against fungus such as Aspergillus, Candida, and Cryptococcus, its liposomal administration minimizes nephrotoxicity [91].

C. Analgesics

1. Liposome Encapsulated Fentanyl, AeroLEF

To deliver a regulated, prolonged release of the fast-acting fentanyl, a liposome-encapsulated version was created (Oprea). AeroLEF is a combination of liposomal and free fentanyl that is aerosolized using nebulizers for postoperative analgesia and pain relief [92].

D. Immunosuppressant

1. Liposomal Cyclosporine

An experimental aerosolized formulation called liposomal cyclosporine A (L-CsA) for inhalation is intended for pulmonary administration to either prevent or treat bronchiolitis obliterans syndrome (BOS) in recipients of lung transplants. When administered through a specialized nebulizer such as the PARI eFlow®, it minimizes adverse effects including nephrotoxicity by achieving high lung concentrations with less systemic exposure than oral or IV cyclosporine [93].

XI. CONCLUSION

Liposomes are versatile drug delivery systems because they can encapsulate both hydrophilic and lipophilic drugs, be surface-modified (e.g., PEGylation or ligand attachment) for targeted delivery to specific sites such as alveolar macrophages or tumor cells, and be engineered to provide controlled or sustained drug release. By altering their composition and surface characteristics, liposomes enable localized delivery and surface-specific targeting in the lungs, making them highly effective for treating a wide range of pulmonary diseases, including tuberculosis, lung cancer, aspergillosis, cystic fibrosis, chronic obstructive pulmonary disease (COPD), asthma, pneumonia, bronchiectasis, pulmonary fibrosis, acute respiratory distress syndrome (ARDS), pulmonary hypertension, emphysema, chronic bronchitis, non-tuberculous mycobacterial infections, and viral lung infections such as influenza.

Liposomal formulations are used across various therapeutic categories, including antibiotics such as Arikayce® (liposomal amikacin for inhalation), Lipoquin™ (liposomal ciprofloxacin), and Pulmaquin™ (dual-release ciprofloxacin). In antifungal therapy, AmBisome® (liposomal amphotericin B) is widely used, while AeroLEF® (liposomal fentanyl) has been developed for analgesic applications.

Liposomal cyclosporine A is an inhalation-based immunosuppressant currently under development and not yet widely marketed.

Acknowledgment

The authors are grateful to the R. C. Patel Institute of Pharmaceutical Education and Research, Shirpur, for facilitating this review through the provision of essential infrastructure, support, and encouragement.

REFERENCES

[1] Agusti, A. and Faner, R., 2019. Lung function trajectories in health and disease. The Lancet Respiratory Medicine, 7(4), pp.358-364.

[2] Murray, J.F., 2010. The structure and function of the lung.

[3] Bordoni, B. and Morabito, B., 2026. Rating Scales for Obstructive Sleep Apnea Syndrome: The Importance of a Comprehensive Assessment. Cureus, 18(1).

[4] Anagnostopoulou, P. and Schittny, J.C., 2021. Anatomy and development of the respiratory system. ERS Handbook of Paediatric Respiratory Medicine, 1.

[5] Finkbeiner, W.E., 1999. Physiology and pathology of tracheobronchial glands. Respiration physiology, 118(2-3), pp.77-83.

[6] Schutte, B.C. and McCray Jr, P.B., 2002. β-defensins in lung host defense. Annual review of physiology, 64(1), pp.709-748.

[7] Byron, P.R. and Patton, J.S., 1994. Drug delivery via the respiratory tract. Journal of Aerosol medicine, 7(1), pp.49-75.

[8] Patton, J.S. and Platz, R.M., 1992. (D) Routes of delivery: Case studies:(2) Pulmonary delivery of peptides and proteins for systemic action. Advanced Drug Delivery Reviews, 8(2-3), pp.179-196.

[9] Colthorpe, P., Fair, S.J., Smith, I.J., Wyatt, D. and Taylor, G., 1995. The influence of regional deposition on the pharmacokinetics of pulmonary-delivered human growth hormone in rabbits. Pharmaceutical research, 12(3), pp.356-359.

[10] Schanker, L.S., 1978. Drug absorption from the lung. Biochemical pharmacology, 27(4), pp.381-385.

[11] Schanker, L.S., Mitchell, E.W. and Brown, R.A., 1986. Species comparison of drug absorption from the lung after aerosol inhalation or intratracheal injection. Drug metabolism and disposition, 14(1), pp.79-88.

[12] Hickey, A.J., 2003. Pharmaceutical inhalation aerosol technology. Crc Press.

[13] (J.M. Borghardt, C. Kloft, A. Sharma, Inhaled therapy in respiratory disease: the complex Interplay of pulmonary kinetic processes, Can.Respir.J. 2018 (2018) 2732017, https://doi.org/10.1155/2018/2732017.).

[14] Fröhlich, E., 2017. Toxicity of orally inhaled drug formulations at the alveolar barrier: parameters for initial biological screening. Drug Delivery, 24(1), pp.891-905.

[15] Costa, A., Pinheiro, M., Magalhães, J., Ribeiro, R., Seabra, V., Reis, S. and Sarmento, B., 2016. The formulation of nanomedicines for treating tuberculosis. Advanced drug delivery reviews, 102, pp.102-115.

[16] G. Poste, Liposome targeting in viva, problems and opportunities, Biol. Cell 47 (1983) 19-37

[17] Mihalko, P.J., Schreier, H. and Abra, R.M., 1988. Liposomes: a pulmonary perspective. Liposomes as drug carriers, pp.679-694.

[18] H. Schreier, Liposome Aerosols, J. Liposome Res. 2 (1992) 145-184.

[19] Byron, P.R., 1990. Respiratory Drug Delivery CRC Press. Inc., Boca Raton, FL.

[20] Gonda, I., 1990. Aerosols for delivery of therapeutic and diagnostic agents to the respiratory tract. Critical reviews in therapeutic drug carrier systems, 6(4), pp.273-313.

[21] Schaad, U.B., Wedgwood-Krucko, J., Suter, S. and Kraemer, R., 1987. Efficacy of inhaled amikacin as adjunct to intravenous combination therapy (ceftazidime and amikacin) in cystic fibrosis. The Journal of pediatrics, 111(4), pp.599-605.

[22] Hall, C.B., McBride, J.T., Walsh, E.E., Bell, D.M., Gala, C.L., Hildreth, S., Ten Eyck, L.G. and Hall, W.J., 1983. Aerosolized ribavirin treatment of infants with respiratory syncytial viral infection: a randomized double-blind study. New England Journal of Medicine, 308(24), pp.1443-1447.

[23] Montgomery, A.B., Luce, J., Turner, J., Lin, E., Debs, R., Corkery, K., Brunette, E. and Hopewell, P., 1987. Aerosolised pentamidine as sole therapy for Pneumocystis carinii pneumonia in patients with acquired immunodeficiency syndrome. The Lancet, 330(8557), pp.480-483.

[24] Schreier, H., Gonzalez-Rothi, R.J. and Stecenko, A.A., 1993. Pulmonary delivery of liposomes. Journal of Controlled Release, 24(1-3), pp.209-223.

[25] McCullough, H.N. and Juliano, R.L., 1979. Organ-selective action of an antitumor drug: pharmacologic studies of liposome-encapsulated β-cytosine arabinoside administered via the respiratory system of the rat. Journal of the National Cancer Institute, 63(3), pp.727-731.

[26] Juliano, R.L. and McCullough, H.N., 1980. Controlled delivery of an antitumor drug: localized action of liposome encapsulated cytosine arabinoside administered via the respiratory system. The Journal of Pharmacology and Experimental Therapeutics, 214(2), pp.381-387.

[27] Wyde, P.R., Six, H.R., Wilson, S.Z., Gilbert, B.E. and Knight, V.E.R.N.O.N., 1988. Activity against rhinoviruses, toxicity, and delivery in aerosol of enviroxime in liposomes. Antimicrobial agents and chemotherapy, 32(6), pp.890-895.

[28] Gilbert, B.E., Six, H.R., Wilson, S.Z., Wyde, P.R. and Knight, V., 1988. Small particle aerosols of enviroxime-containing liposomes. Antiviral research, 9(6), pp.355-365.

[29] Wichert, B.V., Gonzalez-Rothi, R.J., Straub, L.E., Wichert, B.M. and Schreier, H., 1992. Amikacin liposomes: characterization, aerosolization, and in vitro activity against Mycobacterium avium-intracellulare in alveolar macrophages. International journal of pharmaceutics, 78(1-3), pp.227-235.

[30] Debs, R.J., Straubinger, R.M., Brunette, E.N., Lin, J.M., Lin, E.J., Montgomery, A.B., Friend, D.S. and Papahadjopoulos, D.P., 1987. Selective enhancement of pentamidine uptake in the lung by aerosolization and delivery in liposomes. American Review of Respiratory Disease, 135(3), pp.731-737.

[31] Jurima-Romet, M., Barber, R.F., Demeester, J. and Shek, P.N., 1990. Distribution studies of liposome-encapsulated glutathione administered to the lung. International Journal of Pharmaceutics, 63(3), pp.227-235.

[32] Jurima-Romet, M. and Shek, P.N., 1991. Lung uptake of liposome-entrapped glutathione after intratracheal administration. Journal of pharmacy and pharmacology, 43(1), pp.6-10.

[33] Sone, S., Tachibana, K., Shono, M., Ogushi, F. and Tsubura, E., 1984. Potential value of liposomes containing muramyl dipeptide for augmenting the tumoricidal activity of human alveolar macrophages. Journal of Immunotherapy, 3(2), pp.185-194.

[34] Liu, Z.Z., Guo, X.D., Straub, L.E., Erdos, G., Prankerd, R.J., Gonzalez-Rothi, R.J. and Schreier, H., 1991. Lipophilic N-acylpyrazinamide derivatives: synthesis, physicochemical characterization, liposome incorporation, and in vitro activity against Mycobacterium avium-intracellulare. Drug design and discovery, 8(1), pp.57-67.

[35] Schlesinger, R.B., 1985. Comparative deposition of inhaled aerosols in experimental animals and humans: a review. Journal of Toxicology and Environmental Health, Part A Current Issues, 15(2), pp.197-214.

[36] Brain, J.D. and Valberg, P.A., 1979. Deposition of aerosol in the respiratory tract. American Review of Respiratory Disease, 120(6), pp.1325-1373.

[37] Farr, S.J., Kellaway, I.W., Parry-Jones, D.R. and Woolfrey, S.G., 1985. 99m-Technetium as a marker of liposomal deposition and clearance in the human lung. International journal of pharmaceutics, 26(3), pp.303-316.

[38] E. Forsgren. J.A. Modig. C.M.O. Dahlback and B.I. Axelsson, Prophylactic treatment with an aerosolized corticosteroid liposome in a porcine model of early ARDS induced by endotoxaemia, Acta Chir. Stand. 156 (1990) 423-431.

[39] Myers, M.A., Thomas, D.A., Straub, L., Soucy, D.W., Niven, R.W., Kaltenbach, M., Hood, C.I., Schreier, H. and Gonzalez-Rothi, R.J., 1993. Pulmonary effects of chronic exposure to liposome aerosols in mice. Experimental lung research, 19(1), pp.1-19.

[40] Oyarzún, M.J., Clements, J.A. and Baritussio, A., 1980. Ventilation enhances pulmonary alveolar clearance of radioactive dipalmitoyl phosphatidylcholine in liposomes. American Review of Respiratory Disease, 121(4), pp.709-721.

[41] Wright, J.R. and Clements, J.A., 1987. Metabolism and turnover of lung surfactant. American Journal of Respiratory and Critical Care Medicine, 136(2), pp.426-444.

[42] Vanbever, R., Mintzes, J.D., Wang, J., Nice, J., Chen, D., Batycky, R., Langer, R. and Edwards, D.A., 1999. Formulation and physical characterization of large porous particles for inhalation. Pharmaceutical research, 16(11), pp.1735-1742.

[43] Rouge N, Buri P, Doelker E. (1996). Drug absorption sites in the gastrointestinal tract and dosage forms for site-specific delivery. Int J Pharmaceut 136:117–39.

[44] Wadell C. (2002). Nasal drug delivery- in vitro studies on factors influncing permeability and implications on absorption. Faculty of pharmacy in pharmaceutics. Uppsala: Acta Universitatis Upsaliensis.

[45] Patton JS, Byron PR. (2007). inhaling medicines: delivering drugs to the body through the lungs. Nat Rev Drug Discov 6:67–74.

[46] Patton JS. (1996). Mechanisms of macromolecule absorption by the lungs. Adv Drug Deliv Rev 19:3–36.

[47] Wadell C. (2002). Nasal drug delivery- in vitro studies on factors influncing permeability and implications on absorption. Faculty of pharmacy in pharmaceutics. Uppsala: Acta Universitatis Upsaliensis

[48] Brain JD. (1992). Mechanisms, measurement, and significance of lung macrophage function. Environ Health Perspect 97:5–10

[49] Azarmi S, Roa WH, Loebenberg R. (2008). Targeted delivery of nanoparticles for the treatment of lung diseases. Adv Drug Deliv Rev 60:863–75.

[50] Patton JS, Brain JD, Davies LA, et al. (2010). The particle has landed characterizing the fate of inhaled pharmaceuticals. J Aerosol Med Pulmon Drug Deliv 23:s71–87.

[51] Vanbever R, Mintzes JD, Wang J, et al. (1999). Formulation and physical characterization of large porous particles for inhalation. Pharmaceut Res 16:1735–42.

[52] Bangham A, Horne RW. Negative staining of phospholipids and their structural modification by surface active agents as observed in the electron microscope. J Mol Biol 1964;8:660-8

[53] Kulkarni SB, Betageri GV, Singh M. Factors affecting microencapsulation of drugs in liposomes. J Microencapsul 1995;12:229-46

[54] Gregoriadis G. The carrier potential of liposomes in biology and medicine (second of two parts). N Engl J Med 1976;295:765-70

[55] Fendler JH, Romero A. Liposomes as drug carriers. Life Sci 1977;20:1109-20

[56] Sharma A, Sharma U. Liposomes in drug delivery: progress and limitations. Int J Pharm 1997;154:123-40

[57] Eichler H, Senior J, Stadler A, et al. Kinetics and disposition of fluorescein-labelled liposomes in healthy human subjects. Eur J Clin Pharmacol 1988;34:475-9

[58] Thomas D, Myers M, Wichert B, et al. Acute effects of liposome aerosol inhalation on pulmonary function in healthy human volunteers. Chest 1991;99:1268-70

[59] Waldrep JC, Gilbert BE, Knight CM, et al. Pulmonary delivery of beclomethasone liposome aerosol in volunteers. tolerance and safety. Chest 1997;111:316-23

[60] Jaafar-Maalej, C., Elaissari, A. and Fessi, H., 2012. Lipid-based carriers: manufacturing and applications for pulmonary route. Expert opinion on drug delivery, 9(9), pp.1111-1127.

[61] Taylor KMG, Farr SJ. Liposomes for drug delivery to the respiratory tract. Drug Dev Ind Pharm 1993; 19:123.

[62] Taylor KMG, et al. The influence of liposomal encapsulation on sodium cromo glycate pharmacokinetics in man. Pharm Res 1989; 6:633

[63] Saari SM, et al. Regional lung deposition and clearance of 99mTc-labelled beclo methasone-DLPC liposomes in mild and severe asthma. Chest 1998; 113:1573.

[64] Gilbert BE. Liposomal aerosols in the management of pulmonary infections. J Aerosol Med 1996; 9:111.

[65] Finlay WH, Wong JP. Regional lung deposition of nebulized liposome encapsulated ciprofloxacin. Int J Pharm 1998; 167:121.

[66] Suntres ZE, Shek PN. Liposomal a-tocopherol alleviates the progression of paraquat-induced lung damage. J Drug Targ 1995; 2:493.

[67] Juliano RL, McCullough HN. Controlled delivery of an antitumour drug: local ised action of liposome encapsulated cytosine arabinoside administered via the respiratory tract. J Pharmacol Exp Ther 1980; 214:381.

[68] Koshkina NV, et al. Paclitaxel liposome aerosol treatment induces inhibition of pulmonary metastases in murine renal carcinoma. Clin Cancer Res 2001; 7:3258.

[69] Verschraegen CF, et al. Clinical evaluation of the delivery and safety of aero solized liposomal 9-nitro-20(S)-camptothecin in patients with advanced pulmonary malignancies. Clin Cancer Res 2004; 10:2319.

[70] Liu F, et al. Pulmonary delivery of free and liposomal insulin. Pharm Res 1993; 10:228

[71] Gilbert BE, et al. Tolerance of volunteers to cyclosporine A—dilaurylphospha tidylcholine liposome aerosol. Am J Respir Crit Care Med 1997; 156:1789.

[72] Caplen NJ, et al. Liposome-mediated CFTR gene transfer to the nasal epithe lium of patients with cystic fibrosis. Nat Med 1995; 1:39.

[73] Hauser H. Stabilising of liposomes during spray drying. In: Gregoriadis G, ed. Liposome Technology. Vol. 1. 2nd ed. New York: CRC Press, 1993:197.

[74] Crowe LM, et al. Preservation of freeze-dried liposomes by trehalose. Arch Biochem Biophys 1985; 242:240.

[75] Payne NI, et al. Proliposomes: a novel solution to an old problem. J Pharm Sci 1986; 75:325.

[76] Payne NI, Browning I, Hynes CA. Characterization of proliposomes. J Pharm Sci 1986; 75:330.

[77] Perrett S, Golding M, Williams P. A simple method for the preparation of liposomes for pharmaceutical applications: characterization of the liposomes. J Pharm Pharmacol 1991; 43:154.

[78] Stahlhofen W, Gebhart J, Heyder J. Experimental determination of the regional deposition of aerosol particles in the human respiratory tract. Am Ind Hyg Assoc J 1980; 41:385.

[79] Farr SJ, Kellaway IW, Carman-Meakin. Assessing the potential of aerosol generated liposomes from pressurised pack formulations. J Contr Rel 1987; 5:119.

[80] Byron PR, et al. Some aspects of alternative propellant solvency. Respir Drug Deliv 1994; IV:231

[81] Schreier H, et al. Formulation and in vitro performance of liposome powder aerosols. STP Pharm Sci 1994; 4:38

[82] Goldbach P, Brochart H, Stamm A. Spray drying of liposomes for a pulmonary administration. II. Retention of encapsulated materials. Drug Dev Ind Pharm 1993; 19:2623.

[83] Desai TR, et al. A novel approach to the pulmonary delivery of liposomes in dry powder form to eliminate the deleterious effects of milling. J Pharm Sci 2002; 91:482.

[84] Alves GP, Santana MHA. Phospholipid dry powders produced by spray drying processing: structural, thermodynamic and physical properties. Powder Technol 2004; 145:139.

[85] Ferron GA, Kerrebijn KF, Weber J. Properties of aerosols produced with three nebulizers. Am Rev Respir Dis 1976; 114:899.

[86] Taylor KMG, et al. The stability of liposomes to nebulisation. Int J Pharm 1990; 58:57.

[87] Niven RW, Speer M, Schreier H. Nebulization of liposomes II. The effects of size and modelling of solute release profiles. Pharm Res 1991; 8:217.

[88] Gregoriadis, G., 2006. Liposome preparation and related techniques.

[89] Hoy, S.M., 2021. Amikacin liposome inhalation suspension in refractory Mycobacterium avium complex lung disease: a profile of its use. Clinical drug investigation, 41(4), pp.405-412.

[90] Hamblin, K.A., Armstrong, S.J., Barnes, K.B., Davies, C., Laws, T., Blanchard, J.D., Harding, S.V. and Atkins, H.S., 2017. Inhaled liposomal ciprofloxacin protects against a lethal infection in a murine model of pneumonic plague. Frontiers in microbiology, 8, p.91.

[91] Walsh, T.J., Lewis, R.E. and Adler-Moore, J., 2019. Pharmacology of liposomal amphotericin B: an introduction to preclinical and clinical advances for treatment of life-threatening invasive fungal infections. Clinical Infectious Diseases, 68(Supplement_4), pp.S241-S243.

[92] MR, S.J., 1995. Pharmacokinetics of inhaled liposome-encapsulated fentanyl. Anesthesiology, 3, pp.277-284.

[93] Letsou, G.V., Safi, H.J., Reardon, M.J., Ergenoglu, M., Li, Z., Klonaris, C.N., Baldwin, J.C., Gilbert, B.E. and Waldrep, J.C., 1999. Pharmacokinetics of liposomal aerosolized cyclosporine A for pulmonary immunosuppression. The Annals of thoracic surgery, 68(6), pp.2044-2048.