

Modern Approaches in Lung Cancer Management from Herbal Nanomedicine to Artificial Intelligence

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Abstract

Lung cancer continues to be a major global health concern and one of the leading causes of cancer-related mortality worldwide. Despite significant advancements in therapy, there is still a pressing need for safer and more effective therapeutic alternatives; problems such drug resistance, side effects, metastasis, and recurrence continue to impact patient outcomes and quality of life. Examining current advancements in the use of herbal drug-loaded nanoparticles as a novel approach to lung cancer treatment is the goal of this review. A comprehensive analysis of various nanoparticle-based drug delivery systems is given, emphasizing how they can enhance the solubility, bioavailability, and targeted administration of herbal constituents. In order to increase the precision and efficacy of lung cancer treatment, the review also assesses the biomarkers used for targeted therapy and looks at how novel personalized treatment approaches – like wearable electronic patches, robotics-assisted interventions, smartphone-enabled therapies, AI-driven diagnostics, and lung-on-a-chip technologies – can be combined. In conclusion, the future of lung cancer treatment could undergo significant changes because of the integration of nanotechnology and personalized medicine.

Keywords: Lung cancer, herbal medicine, nanoparticles, artificial intelligence, lung cancer biomarkers

INTRODUCTION

Lung cancer is the primary cause of cancer-related fatalities globally, accounting for 1.82 million deaths (18.7%) and 2.48 million new cases (12.4%), according to GLOBOCAN 2022. It is still the most frequent cancer worldwide, but its incidence is rising in women while it is decreasing in males because of tobacco control [1]. Small cell and non-small cell lung cancer (NSCLC) are the two primary forms of lung cancer; NSCLC accounts for more than 85% of cases. The primary cause is smoking; additional dangers include second-hand smoke, radon, pollution, genetics, and asbestos [2]. Small-cell lung cancer (SCLC), including oat cell type, grows rapidly. Key risk factors are smoking, genetics, urbanization,

and environmental exposures like asbestos and arsenic. In 2020, WHO reported 180 million deaths and 2.21 million cases [3]. Lung cancer treatment depends on the size and location of the tumor. Options include surgery, radiation, photodynamic therapy, chemotherapy, and targeted therapy [4]. More than 81% of patients with non-small cell lung cancer cannot have surgery. Platinum-based chemotherapy is still the norm for advanced stages, despite its mixed results. However, side effects from radio chemotherapy and medication resistance make treatment more difficult [5]. Recent advances in illness screening have introduced immunotherapy and targeted therapy. Despite FDA-approved immune checkpoint inhibitors, high costs and serious side effects limit their widespread clinical use (Figure 1) [6].

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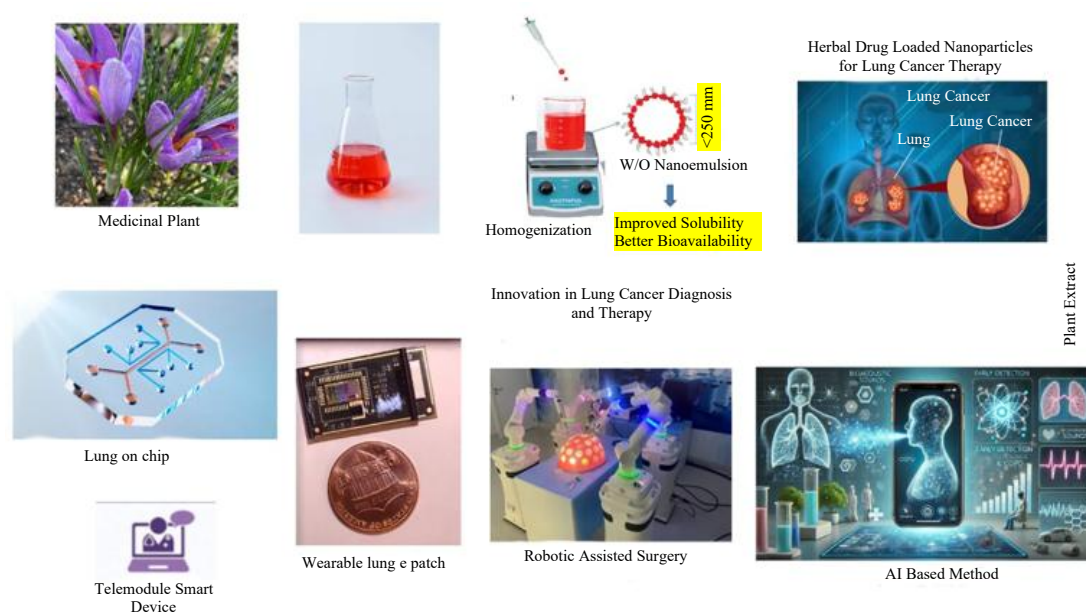


Figure 1. Graphical representation of lung cancer management.

The WHO reports that 80% of rural communities get their basic healthcare from inexpensive, less harmful herbal remedies. Herbs are also used in conjunction with chemotherapy by 77% of patients with lung cancer [7]. Through phytochemicals that target cancer cells, improve therapy, lessen side effects, and increase survival, plants can treat lung cancer [8]. Medicinal herbs fight cancer by inducing apoptosis, blocking angiogenesis, altering reactive oxygen species ROS, damaging mitochondria, and inhibiting nuclear factor kappa B NFkB, activator protein AP-1, cyclooxygenase 2 COX-2, epidermal growth factor receptor EGFR, human epidermal growth factor receptor 2 HER2, Jun N-terminal kinases JNK, and cell proliferation [9]. Lung cancer may be treated with natural materials; however, the bioavailability and efficacy of herbal remedies are limited by their poor solubility and absorption [10]. Because of their small size and surface customization, nanoparticles help cancer treatment by facilitating better medication administration through both active (ligand-targeted) and passive (size-based) targeting [11].

Herbal medications in nanoparticle form enhance cancer treatment by improving solubility, bioavailability, and reducing toxicity, leading to better efficacy and patient compliance. The concept of “therasurgynostic” combines diagnosis, therapy, and surgery using advanced detection, new drugs, and robotic surgery to improve lung cancer outcomes and support global cancer control.

BIOMARKERS TARGETED FOR LUNG CANCER TREATMENT

T-cells and tumor cells have proteins called immune checkpoints that help regulate immune responses. When these proteins interact, tumor cells send an “off” signal to T-cells, stopping them from attacking the cancer [12]. Chemotherapy for advanced non-small cell lung cancer (NSCLC) has a dismal prognosis; however, immunotherapy and targeted medicines, which are guided by biomarkers, such as EGFR and ALK, greatly improve results through individualized treatment [13]. Targetable mutations are present in about 60% of advanced non-small cell lung cancers; approved or newly discovered therapeutic targets include EGFR, ALK, and ROS1 [14].

Molecular Target

EGFR

EGFR p.L858R and EGFR Exon 19 Deletion

EGFR mutations are found in about 10% of NSCLC patients; NGS finds more variations than PCR or low-sensitivity Sanger sequencing [15]. Patients with EGFR-mutant cancers now live over three

years with next-gen EGFR therapies, but resistance especially the T790M mutation limits their long-term effectiveness [16]. Osimertinib, a third-generation EGFR inhibitor, is authorized as a first-line treatment for EGFR-mutant lung cancer because it overcomes resistance and enhances response and survival [17].

EGFR Exon 20 Insertion Mutations

About 10% of EGFR mutations are exon 20 insertions causing resistance to approved EGFR-TKIs, limiting effective treatment options [18]. Current inhibitors are ineffective against EGFR exon 20 insertions; new research has revealed mechanisms that encourage the creation of novel medications that specifically target these mutations [19].

ALK

About 3–13% of NSCLC cases have ALK rearrangements, mainly the EML4-ALK fusion from a chromosomal inversion, identified in 2007 [20]. This fusion causes constant ALK kinase activation, promoting cancer growth. The main variants are V1 (54.5%), V3a/V3b (34%), V2 (10%), and V5a (1.5%). ALK inhibitors effectively shrink tumors, making this fusion a crucial treatment target [21].

MET

Many lung malignancies have MET exon 14 skipping, while SCLC cell lines and tumors are the primary source of MET juxtamembrane alterations [22]. There aren't many FDA-approved MET inhibitors for NSCLC, but it's still difficult to determine which patients would benefit because there aren't any trustworthy prognostic biomarkers [23].

Signalling Pathways Targeting Tumor Immunity

PD-L1 and PD1

When PD-1 on T/B cells binds to programmed death ligand 1 (PD-L1/PD-L2), it suppresses immunity; preventing this restores T-cell attack on malignancies such as SCLC [24]. Antibodies, such as durvalumab and pembrolizumab that target PD-1/PD-L1, stimulate the Ras/MEK/Erk and PI3K/Akt pathways, increasing T cell activation and tumor cell death in non-small cell lung cancer [25].

CTLA-4

T-cell activation is blocked by Cytotoxic T-Lymphocyte Associated Protein 4 CTLA-4; ipilimumab suppresses CTLA-4. Nivolumab + ipilimumab increased median survival to 17.1 months with 29% 4-year survival in advanced non-small cell lung cancer [26].

Signalling Pathways Targeting Angiogenesis

PDGF

Platelet Derived Growth Factor PDGF signaling (PDGFR α in tumors, PDGFR β in stroma) is how lung cancer spreads. A high PDGFR indicates poorer results. Through altering the microenvironment, inhibitors, such as MEDI-575, decrease the growth of tumors [27].

VEGF

According to Mattern et al. (1996), VEGF Vascular Endothelial Growth Factor promotes angiogenesis in non-small cell lung cancer. Combining the anti-VEGF-A antibody bevacizumab with immunotherapy or chemotherapy improves survival [28].

NANOTECHNOLOGY TARGETED IN LUNG CANCER

Medicinal chemicals are often encapsulated in or attached to nanoparticles (NPs) smaller than 100 nm to improve stability and targeting. These NPs serve as effective theranostic agents for cancer by enabling simultaneous diagnosis, imaging, and therapy due to their small size, high surface area, and customizable surfaces. Their size allows deep tissue penetration and easy cell entry, enhancing drug bioavailability. Drug release and dosage can be optimized by modifying the polymer properties of the NPs. Nanotechnology enables dual drug targeting, enhancing drug concentration in tumors while

minimizing harm to healthy tissues, for instance, hyaluronic acid modified nanoparticles co-deliver erlotinib and bevacizumab for high tumor targeting with low toxicity. Similarly, bevacizumab-coated gefitinib nanoparticles effectively target NSCLC tumors and slow growth. Overall, nanotechnology shows great potential in overcoming resistance to targeted therapies [29].

Passive and Active Targeting

Drug conjugated nanoparticles enter tumors through leaky arteries by taking use of the Enhanced Permeability and Retention effect EPR effect. While surface ligands, like peptides and antibodies, target cancer cells for specific therapy administration through receptor-mediated endocytosis, smaller sizes improve penetration [30].

Lymphatic Drug Delivery

By avoiding mucociliary clearance and macrophage uptake, targeting pulmonary lymphatics with 10–100 nm nanoparticles by inhalation or interstitial delivery enhances medicine retention and minimizes side effects for lung cancer treatment [31].

Types of Nanoparticles Used for Lung Cancer Therapy

- *Inorganic Nanoparticles*: For example, Gold (Au), Silver (Ag), Aluminium (Al), Zinc (Zn), Copper (Cu), Iron (Fe), Cadmium (Cd) Copper Oxide (CuO), Titanium dioxide
- *Organic Nanoparticles*: For example, Liposomes, Dendrimers, Micelles, Cyclodextrin, Nanogel, Compact Polymer

Gold Nanoparticles (AuNPs)

Because of their stability, low toxicity, and biocompatibility, gold nanoparticles (3–200 nm) are prized. They cure and diagnose malignancies of the lung, breast, cervical, liver, and rectal regions. They are also used as radiosensitizers, contrast agents, medication transporters, and photothermal agents [32].

Zinc-Based Lung Cancer Therapy

FDA approved for medication delivery, zinc oxide nanoparticles (ZnONPs) shield macrophages from chemotherapy. When *Aspergillus Niger* coupled with DOX, biogenic ZnONPs efficiently target and destroy A549 lung cancer cells [33].

Silver-Based Lung Cancer Therapy

The therapeutic benefits of silver nanoparticles are influenced by their size and form. By focusing AgNPs on cancerous cells, reducing toxicity, and shielding healthy tissues from reactive oxygen species, targeting approaches improve the therapy of cancer [34, 35].

HERBAL NANOMEDICINE IN LUNG CANCER

New medications that target tumors are required to fight cancer; through processes, like autophagy, apoptosis, cell growth suppression, and cancer pathway modification, herbal medications exhibit potential. Thevetinbioside (THB), a substance found in *Thevetin peruviana* (TPKS), has potential pharmacological effects such as anti-inflammatory qualities for skin conditions and potential anticancer advantages. THB shows strong cytotoxic activity in P53 wild-type A549 and H460 NSCLC cells, in a dose- and time-dependent manner. It inhibits tumor growth by inducing apoptosis, marked by increased Bad, cleaved caspase-3, and cleaved PARP, and decreased BCL-XL expression. Through cell cycle arrest and death, thymol exhibits dose and time dependent antiproliferative effects on A549 cells. However, its application is limited by its poor bioavailability and solubility. Absorption is further decreased when combined with flavonoids. Formulations of nanoparticles present a viable way to improve delivery, stability, and synergistic effectiveness in the treatment of cancer [37].

HERBAL NANOMEDICINE CHALLENGES AND BENEFITS

Improved Solubility

Diosmin's oral administration and tumor-targeting effectiveness were improved by pH-modulated gliadin lactoferrin nanoprecipitation, whereas PVA nanosuspensions improved solubility, release, and aromatase inhibition [38].

Sustained Release

Using hydrophobic ion pairing with SDC or SLS, Abdelmoneem et al. increased berberine administration by lowering burst release and facilitating longer, controlled release through better micelle or nanoparticle entrapment [39].

Increased Stability

Despite environmental sensitivity, regulated release (21.8%) in intestinal fluid at 37°C is made possible by nano-encapsulation in solid lipid nanoparticles, which improves bioavailability for herbal drugs like Epigallocatechin gallate EGCG that have stability problems [40].

Improved Bioavailability

By increasing solubility, dispersion, and bioavailability and facilitating improved microscopic body mobility, nanoparticles and nanoemulsions improve the absorption of herbal remedies [41].

Enhanced tumor targeting by lowering tumors and Ki-67, dual-targeted nanocapsules containing quercetin-sorafenib increased efficacy and safety (Table 1) [42].

Table 1. Nanostructures containing herbal drugs used for treating lung cancer.

S. N.	Nanostructure	Herbs	Bioactive compound	Biomarkers	Ref.
1.	Gold and silver NPs	Platycodi Radix (<i>Platycodon grandiflorum</i>)	Platycodin D (PLD)	PD-L1	[43].
2.	Silver NPs	<i>Morus alba</i> (white mulberry)	Prenylate flavonoids like morusin	STAT3, NF-κB, caspases, EGFR, PDGFR, ROS, etc.	[44].
3.	Gold nanoclusters	Most fruits and vegetables	Kaempferol (flavonoid)	TNF-α, IL, NF-κB, Akt, VEGF, AP-1, PIK3R1, AKT1, EGFR, and IGF1R	[45].
4.	Lipid NPs	Found in many essential oils of plants	Geraniol (GOH)	Inhibit HMGCR	[46].
5.	Biocompatible lipid NPs	<i>Lippia alba</i> and <i>Clinopodium nepeta</i> essential oils	Monoterpenes (Limonene in <i>L. alba</i> and pulegone in <i>C. nepeta</i>)	Increase ROS generation	[47].
6.	Core shell Lipid polymer hybrid NPs (LPNs)	Skin of grapes, raspberries, mulberries	Resveratrol (RSV)	VEGF, caspase-3	[48].
7.	Poly (lactic-co-glycolic acid)-based AE NPs (nanoAE)	<i>Aloe vera</i> and <i>Rheum officinale</i>	Aloe-emodin (AE)	Caspase-3, poly (ADP-ribose) polymerase (PARP), caspase-8, and caspase-9	[49].
8.	Poly (lactic acid) poly (ethylene glycol) (PLA-PEG) NPs	Green vegetables like broccoli, cabbage, celery, spinach	Luteolin (flavonoid)	PD-L1	[50].
9.	Oil nanoemulsions	<i>Piper nigrum</i> (black pepper)	Piperine	Wnt, NF-κB, cAMP response element-BP, TF-2, PPAR- γ, human G-quadruplex DNA,	[51].
10.	Nanoemulsions	Green tea	Epigallocatechin-3-gallate (EGCG)	ROS, NF-κB, Akt, VEGF, PPAR, Bcl-2, MAP kinases	[52].

DRUG DELIVERY SYSTEMS ENTRAPPING NATURAL BIOACTIVE COMPOUNDS FOR CANCER

Over the past 20 years, novel drug delivery systems (NDDS) have been created with the goals of enhancing medication bioavailability, minimizing adverse effects, and halting drug degradation. By

delivering medications straight to the intended location, these methods improve solubility, stability, therapeutic impact, and patient convenience. Additionally, NDDS aid in the regulation of immunogenicity, pharmacokinetics, and pharmacodynamics. Drug release can happen through active targeting, which employs particular ligand receptor interactions for precise delivery, or passive targeting, which involves accumulation in tumor tissues because of increased vascular permeability (Table 2) [53].

Table 2. Herbal plants exhibiting anticancer activity [54].

Plant name	Part of plant	Family	Phytochemicals	Therapeutic anticancer action	Mechanism of action
<i>Artemisia capillaries thunb</i> (Wormwood)	Unexpanded flower heads	Asteraceae	Essential oil, aantonin, artemisinin	Antioxidant, Anticancer effect in lung cancer	• Preventing cell division and triggering apoptosis. • Decrease in proliferating cell nuclear antigen (PCNA) expression. • Preventing the PI3K/AKT connection.
<i>Catharanthus roseus</i> (L.). G. Don. (Vinca, periwinkle)	Dried whole plant	Apocynaceae	Vinca alkaloids (Vincristine, vinblastine, leurosine, vindesine, and vinorelbine), ajmalicine, catharanthine, vindoline	Anticancer, and antineoplastic	• Cell cycle arrest by spindle formation inhibition.
<i>Ferula assa-foetida</i> L. (Asafoetida)	Resin	Apiaceae	Coumarin compounds, bsitosterol and oleic acid.	Antitumor activity in colon cancer, liver cancer, ovarian cancer, and lung cancer	• Hindering gene mutation. • Influencing enzyme activity, stopping DNA deterioration. • Influencing cell division.
<i>Lagenaria siceraria</i> (molina) Standl (Bottlegourd)	Aerial parts	Cucurbitaceae	Vitamin C, b-carotene, vitamin group B, saponins, and cucurbitacin	Breast cancer, and lung cancer treatment	• Cell-cytotoxic
<i>Prunus armeniaca</i> L. (Apricot)	Wood, kerne, seed	Rosaceae	Hydrogen cyanide, camphene, benzaldehyde, hexanol, g-butyrolactone, g-terpinene	Anticancer effect in lung cancer, and breast cancer patients	• Induction of apoptosis. • Decrease in Bax and c-FLIP gene expression
<i>Zingiber officinale</i> Roscoe (Ginger)	Rhizomes	Zingiberaceae	Volatile oil, fat, fiber, Starch, inorganic material, residual moisture and acrid resinous matter.	Anti-cancer and anti-inflammatory agents.	• Suppressing the proinflammatory tumor necrosis factor (TNF)-alpha to deactivate NF-kB.
<i>Taxus brevifolia</i> Nutt (Western yew)	Dried leaves, bark and root	Taxaceae	Taxane, taxol, cephalomannine, 10-diacetyl baccatin, docetaxel and paclitaxel	Lung carcinoma, gastric and cervical cancers and also carcinomas of head, breast, ovary, skin, neck, prostate and colon	• Stopping tubulins from de-polymerizing.
<i>Curcuma longa</i> L. (Turmeric)	Dried as well as fresh rhizome	Zingiberaceae	Curcumin, and curcuminoids	Antitumor activity in lung cancer	• AMPK Activation and NF-κB inhibition.

BIOPOLYMER BASED NANOCARRIERS

Natural, biocompatible, and biodegradable macromolecules, biopolymers are perfect for delivering drugs, particularly when it comes to encasing phytochemicals. They facilitate safe tissue interaction and

are eco-friendly. Biopolymers in nanocarriers allow for targeted delivery, controlled release, and enhanced solubility of poorly soluble medications, which are helpful in anti-cancer and anti-obesity treatments. Because of its mucoadhesive, pH-responsive, and positively charged qualities, chitosan is noteworthy for improving the absorption of oral medications. Alginate and calcium combine to generate gels that shield hydrophilic medications and allow for prolonged release. Because gelatin is biocompatible and thermo sensitive, it can be used in long-term, temperature-responsive drug delivery systems [55].

Different Nanotechnology-Based Carrier Platform for the Efficient Delivery of Anticancer Phytochemical

Liposomes

Delivery is enhanced by liposomal medications such as DOXIL and Marqibo. Liposomal paclitaxel has the potential to improve the treatment of non-small cell lung cancer, while lipoplatin lessens kidney damage [56].

Solid Lipid Nanoparticles

By improving solubility, stability, oral bioavailability, controlled release, and targeting via the EPR effect without the need for organic solvents, solid lipid nanoparticles (120–200 nm) enhance the delivery of phytochemicals [57].

Polymeric Micells

Anticancer medications have poor oral absorption and require toxic solvents IV. PEG block copolymer micelles improve solubility, delivery, stability, circulation time, and biocompatibility because of their hydrophilic shells and hydrophobic cores [58].

Dendrimers

Dendrimers are drug delivery nanoparticles that resemble trees. Bioavailability is improved by targeting peptides with PEGylation. Lung cancer is decreased and medication retention is enhanced by doxorubicin conjugated dendrimers [59].

Nanostructured Lipid Carriers (NLCs)

Solid and liquid lipids are used to create nanostructured lipid carriers (NLCs), which improve drug loading, lower crystallinity, and regulate release. Compared to traditional carriers, they provide superior phytochemical encapsulation, stability, solubility, protection, and targeted delivery [60].

Magnetic Nanoparticles (MNP)

In biological applications, magnetic nanoparticles particularly those based on iron oxide improve imaging, transport, and stability by providing low toxicity, high magnetism, durable coatings, functionalization, and external responsiveness [61].

TECHNIQUES

The techniques commonly used for the formulation are:

High-Pressure Homogenization Method

High-pressure homogenization is a dependable technique for producing emulsions, SLNs, and lipid-based drug carriers on a large scale by reducing particle size to the nano range using high shear stress at 100–2,000 bar [62].

Solvent Extraction Method

This process uses a stabilizer and a solvent that is partially water soluble to produce an oil-in-water emulsion. Evaporation or emulsification diffusion, which are both methods of solvent extraction, are the two ways that solvents are removed. Nowadays, the emulsification diffusion process is widely applied. The polymer precipitates as tiny nanospheres because of the solvent for the polymer, which is poorly miscible with the dispersion phase, slowly diffusing and evaporating while stirring (Nahar M, et al., 2006) [63].

Solvent Evaporation

By emulsifying polymer solutions in volatile solvents, such as ethyl acetate and then evaporating the solvent, solvent evaporation creates polymer nanoparticles. Particle size (60–200 nm) is influenced by variables such as stabilizer concentration, homogenization speed, and polymer quantity [64].

Supercritical Fluid Technology

By lowering solvent residues and their negative effects on the environment, researchers are investigating supercritical fluids as environmentally acceptable solvents to produce high purity PNPs [65].

Self-Assembly Methods

The physical process of self-assembly occurs when pre-existing disordered atoms, molecules, or components arrange themselves into controlled nanoscale structures through chemical or physical processes without the assistance of an outside source [66].

Co-Precipitation Method

Co-precipitation creates superparamagnetic, highly magnetic colloids by combining an iron source with a NaOH nanoemulsion, then lysing the acetone and washing it with ethanol to create magnetite nanoparticles [67].

INNOVATIVE LUNG CANCER THERANOSTICS

The first method of treating lung cancer was lobectomy, which was shown to be more effective than sub lobar resection in 1995. Less intrusive therapies are now preferred, particularly for fragile older persons with co-morbidities or impaired lung function, since ubiquitous CT scanning can identify early-stage nodules. The desire for kinder treatments outside of surgery is also fuelled by hereditary predispositions to certain lung malignancies in Asia [68].

Electrical LCT

By increasing cell membrane permeability by electric shocks, such as electroporation, electrical stimulation in cancer therapy improves treatment outcomes. It enhances other physical stimuli such as magnetic fields, heat, light, and radiation [69]. In NSCLC, electrochemotherapy (ECT) is safe, efficacious, and acceptable. It uses reversible electroporation to improve drug absorption. Paclitaxel and tumor-treating fields (TTFields) increase anticancer effects by interfering with cancer cells' mitosis [70].

Lung-on-a-Chip

Organ-on-a-chip provides a superior substitute for animal testing by simulating human organs using microscale channels. Lung-on-a-chip helps with drug testing in realistic settings by simulating diseases like non-small cell lung cancer. In 2022, we assessed EGFR-targeted treatments using NCI-H1650 and HUVECs. The model developed by Hassell et al. provides a practical and economical tool for cancer research while also advancing knowledge of treatment response and disease progression [71].

Robotics/Drone-Based Lung Cancer Treatment

The use of minimally invasive surgery (MIS) to treat lung cancer has increased, particularly in its early stages. For advanced patients (N2), open surgery is still the norm, but robotic-assisted techniques are becoming more popular because of their improved visualization and accuracy. Research, such as Herb's review, demonstrates that MIS provides similar survival rates, a quicker recovery, and fewer problems [72].

Drone Technology in Healthcare Delivery

Unmanned aerial vehicle UAVs, sometimes known as drones, have significant advantages in the delivery of healthcare. Abeygunawardana et al. created an e-medic platform that delivers drugs via self-governing drones. It uses REST APIs to manage drone navigation and prescriptions and is integrated with a web application. For effective delivery, computer vision makes it possible to avoid obstacles and choose the best route [73].

Artificial Intelligence (AI)-Based LCT

By improving early diagnosis, monitoring, and prognosis through high-precision imaging and pattern recognition, artificial intelligence (AI) is transforming the study of lung cancer. Deeper understanding of the biology of lung cancer and more individualized treatment plans are made possible by AI-driven methods that integrate several omics field, including pathology, radiomics, immunogenomics, proteomics, and genomics, to unravel complex molecular and genomic landscapes [74].

By precisely recognizing nodules in imaging, forecasting risk, and employing deep learning to find important genetic abnormalities, like EGFR and KRAS, AI, and ML, improve the treatment of lung cancer. Through natural language processing and genomic analysis, these technologies speed up precision medicine, enhance early diagnosis, and enable individualized treatments.

AI and ML in Lung Cancer Detection and Diagnosis

AI and machine learning improve the identification of lung cancer by accurately evaluating X-rays and CT scans. Because of asymptomatic early stages and inefficient screening systems, late detection is still common even though early diagnosis greatly increases survival rates.

AI and ML Applications in Lung Cancer Management

By predicting therapy outcomes, customizing medication combinations, and evaluating genomic data to find targeted treatments, artificial intelligence (AI) significantly improves lung cancer care by maximizing recovery and reducing side effects through precise, individualized medicine based on each patient's distinct molecular profile [75].

CONCLUSION

Lung cancer is one of the deadliest diseases worldwide due to late diagnosis and the limited effectiveness of conventional treatments such as chemotherapy and radiation therapy. Recently, herbal medicines have gained attention in cancer research because they are natural and cause fewer side effects. Plant-derived compounds, like curcumin, paclitaxel, and resveratrol, show strong anticancer potential but face challenges such as poor solubility and low absorption. Nanotechnology helps overcome these limitations by encapsulating herbal compounds in nanoparticles, improving their stability and bioavailability. Nanoparticles, like gold, silver, zinc oxide, and diamond, enable targeted drug delivery. Emerging technologies, such as AI, biosensors, and lung-on-a-chip models, also support early detection and personalized treatment.

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