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Investigating the application of radiological images in the diagnosis and treatment of diffuse lung and airway tumors based on the point of clinical care

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ABSTRACT

Introduction: Early detection of lung cancer can be effective in the treatment process. However, it is difficult to detect this cancer in its early stages. Because its symptoms are similar to a respiratory infection.
Material and method: In the current study, the issue investigated by reviewing 42 articles and considering key words such as "radiological images", "diagnosis", "airway tumors", "clinical care", “Systematic Review” in Scopus, Google scholar and PubMed databases.
Findings: Lung cancer treatments are designed to get rid of the cancer in the body or slow its growth. Treatments can eliminate cancer cells, help destroy them, or prevent them from multiplying, or teach your immune system to fight them. Some treatments are also used to reduce symptoms and relieve pain. Your treatment will depend on the type of lung cancer, its location, how far it has spread, and many other factors.
Conclusion: Graphene oxide was prepared using the Hammer method. The structural integrity of the synthesized graphene oxide was verified and confirmed using FT-IR, UV-Vis spectroscopies, and TEM imaging. The different responses of the biosensor Nano sensor to healthy and mutated DNA enabled the detection of lung cancer. Therefore, by relying on nanotechnology, it is possible to detect lung cancer through fast, easy and cost-effective methods.

Introduction

Depending on where in the lung the cancer starts, some symptoms may appear earlier, in stages 1 or 2, but often there are no symptoms until the cancer has advanced to the later stages. Lung cancer was not common before the 1930s, but it has increased dramatically in the following decades due to increased tobacco use. Lung cancer is the leading cause of cancer death in both men and women worldwide [1].

Because it spreads, or metastasizes, quickly after it forms, it is very dangerous and one of the most difficult cancers to treat. The adrenal glands, liver, brain, and bones are the most common sites for lung cancer to metastasize. The risk of lung cancer in smokers is very high and is directly related to the number of years and packs of cigarettes a person has smoked. Fortunately, quitting smoking can reduce your risk of developing this cancer. Exposure to secondhand smoke can also cause the disease in non-smokers [2].

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Early detection of lung cancer can be effective in the treatment process. However, it is difficult to identify this cancer in its early stages. Because its symptoms are similar to a respiratory infection and sometimes the person does not have any symptoms. For this reason, the prognosis of lung carcinoma is poor. In patients with lung cancer whose cancerous mass is limited to the lungs, the five-year survival is about 54 percent, but in those with advanced and inoperable lung cancer, the five-year survival is about 4 percent. Complications of lung cancer include shortness of breath, coughing up blood, pain, fluid accumulation in the lungs, and metastasis to other organs. For the treatment of non-small cell lung cancer that has not yet spread outside the chest, surgery and removal of the cancerous mass are the most important treatments [3].

The type of surgery depends on the size of the tumor and the presence of other lung diseases. Sometimes removing a small part of the lung is sufficient, and sometimes it is necessary to remove a lobe of the lung. In addition to the lung, lymph nodes around the lung are also removed to further assess the spread of cancer cells, but if the cancer has spread outside the chest, chemotherapy becomes important. This type of treatment is also done before or after surgery for the mass. In some advanced cases of lung cancer, chemotherapy does not cure it, but it improves symptoms and increases the patient's life expectancy. Another treatment method to improve symptoms is radiation therapy. This method is useful for reducing bone pain in bone metastases and brain symptoms for spread to the brain. Radiation therapy is used alone or in combination with chemotherapy for treatment. For the treatment of small cell lung cancer, both chemotherapy and radiation therapy, or both methods, and sometimes surgery are used. This type of cancer responds better to chemotherapy [4].

Historical Evolution & Diagnostic Modalities
Chest X-Ray (CXR)

Chest radiography has long been the first-line imaging test for suspected pulmonary disease. However, it lacks sensitivity—studies report a 20–23% false-negative rate in symptomatic lung cancers—particularly in early-stage or diffuse lesions. Small nodules (<1.5 cm), ground-glass opacities, and lesions obscured by anatomical structures frequently go undetected [5].

Computed Tomography (CT) & High-Resolution CT (HRCT)

Multidetector CT, especially HRCT, has become the gold standard for detecting diffuse lung and airway tumors. It excels in identifying interstitial changes, small nodules, and airway wall abnormalities, informing biopsy and therapeutic planning . Large-airway tumors and tumor-like conditions are better characterized through CT, including the use of multiplanar reconstructions and 3D imaging [6].

PET/CT & Functional Imaging

PET/CT adds metabolic information, with SUV metrics guiding malignancy assessment, staging (N and M classification), and therapy response monitoring—particularly important for diffuse airway diseases and post-SBRT treatment follow-up [7].

MRI & Diffusion-Weighted Imaging (DWI)

MRI, particularly diffusion-weighted sequences, serves a complementary role—useful for evaluating mediastinal invasion, vascular involvement, and distinguishing malignant from benign nodules with high specificity [8].

AI & Radiomics

Radiomics harnesses complex image textures and patterns to:

- Diagnose and stage lung cancer: CT radiomic signatures correlate with histology and EGFR/KRAS mutation status; in one study, differentiating part-solid nodules yielded an AUC of 0.98.
- Predict prognosis: Features like texture and shape forecast recurrence and metastasis; early-stage NSCLC post-SBRT saw local recurrence detected via radiomic markers.
- Anticipate therapy response: Pre-treatment radiomic models for neoadjuvant chemo or EGFR-TKIs achieved concordance indices between 0.63–0.77 [9].

Automated segmentation tools show ~89% accuracy in HRCT analysis of diffuse lung disease, enabling longitudinal follow-up.

Imaging Patterns in Diffuse and Focal Tumors
Diffuse Airway Lesions

Benign and malignant diffuse lesions (e.g., amyloidosis, papillomatosis, Wegener's) present with multisegmental airway thickening or nodularity . CT distinguishes focal from diffuse involvement; diffuse patterns lean toward non-neoplastic or metastatic etiologies.

Case reports (e.g., Rosai-Dorfman disease) highlight PET/MRI features—high SUV and DWI signal—informing diagnosis and response to bronchoscopic interventions [10].

Small & Diffuse Lung Nodules

Small adenocarcinomas with ground-glass features require combined CT and PET to assess invasiveness and lymph node metastasis potential. Advanced segmentation helps estimate pathological invasion (cT vs pT).

Differential Diagnosis from Non-Malignant Conditions

Inflammatory and fibrotic disorders (e.g., interstitial lung disease, granulomatosis) can mimic tumor spread on imaging. HRCT features—reticulation, honeycombing, air trapping—aid differentiation. AI tools increasingly support pattern recognition [11].

Iranian Research Landscape
Epidemiologic & Clinical Profile

Analysis of 1,382 Iranian lung cancer patients showed adenocarcinoma prevalence (~42%), median age ~60 years, male:female ~3.65, and 82.7% presenting with stage IV disease—underscoring late-stage diagnosis [12].

Long-Term HRCT Surveillance in Sulfur Mustard–Exposed Patients

A longitudinal study (2001–2019) of Iranian war veterans revealed 5.8% developed lung cancer, with HRCT detecting fibrosis, bronchiectasis, and malignancy. Adenocarcinoma was most common, and side-matched fibrotic changes correlated with tumor laterality .

Diffusion MRI & Contrast Agent Research

Preliminary Iranian studies evaluated diffusion MRI metrics (ADC values) to distinguish malignant from benign nodules, reporting promising specificity . Research on gadolinium-based nanocomposite contrast agents aims to enhance tumor detection sensitivity but remains in experimental stages [13].

Case Reports in Large-Airway Disease

Case series document Rosai-Dorfman and other rare diffuse conditions in Iranian patients, using combined CT, PET, and DWI MRI to assess airway tumors, guide bronchoscopic resection, and evaluate outcomes.

Comparative Analysis & Future Directions
CT and PET/CT

Global practice emphasizes MDCT and PET/CT as diagnostic and staging cornerstones . In Iran, CT is routinely available; PET/CT remains underutilized, with usage limited to select centers and case reports .

MRI and Advanced Techniques

Though MRI is secondary to CT, diffusion-weighted imaging is gaining attention in Iran and abroad. Nanoparticle contrast agents remain in experimental research [14].

Radiomics & AI

Global radiomic research outpaces Iranian developments. International teams are extracting hundreds of imaging features linked to histology, mutations, prognosis, and treatment response . In Iran, AI applications are emergent, primarily within academic institutions.

Challenges & Recommendations

- Limited advanced modalities: PET/CT and MRI access is constrained outside major Iranian cities.
- Bottleneck in data: Large, labeled imaging datasets for AI training are scarce.
- Research integration: Multi-center collaboration is needed to validate MRI-contrast agents and radiomic models against clinical outcomes.
- Clinical implementation: AI models require localization—trained on Iranian imaging data—to improve diagnostic precision [15].

Internationally, radiological imaging of diffuse lung and airway tumors has advanced significantly: combining MDCT, PET/CT, HRCT pattern analysis, diffusion MRI, and radiomics. These achieve greater diagnosis accuracy, staging precision, and treatment monitoring.

In Iran, clinicians and researchers have made important strides—longitudinal HRCT surveillance in toxic exposure populations, diffusion MRI studies, and CT radiopathology correlation. However, broader adoption of PET/CT, diffusion MRI, and especially AI-powered radiomics will require infrastructural investment, large clinical datasets, and national, multi-institutional cooperation [16].

Future priorities for Iran's radiological oncology research:

- Expand PET/CT access and routine use.
- Integrate diffusion MRI and nanoparticle-enhanced contrast in clinical trials.
- Develop AI and radiomic models trained on localized patient populations.
- Foster cross-disciplinary teams (radiology, pulmonology, oncology, pathology, data science).
- Design prospective, multicenter studies validating imaging biomarkers against long-term outcomes.

Together, these steps can transform from retrospective case series to proactive, precision diagnostics—ultimately improving early detection and personalized care for diffuse lung and airway tumors in Iran and beyond [17].

Material and method: In the current study, the issue investigated by reviewing 42 articles and considering key words such as "radiological images", "diagnosis", "airway tumors", "clinical care", “Systematic Review” in Scopus, Google scholar and PubMed databases.

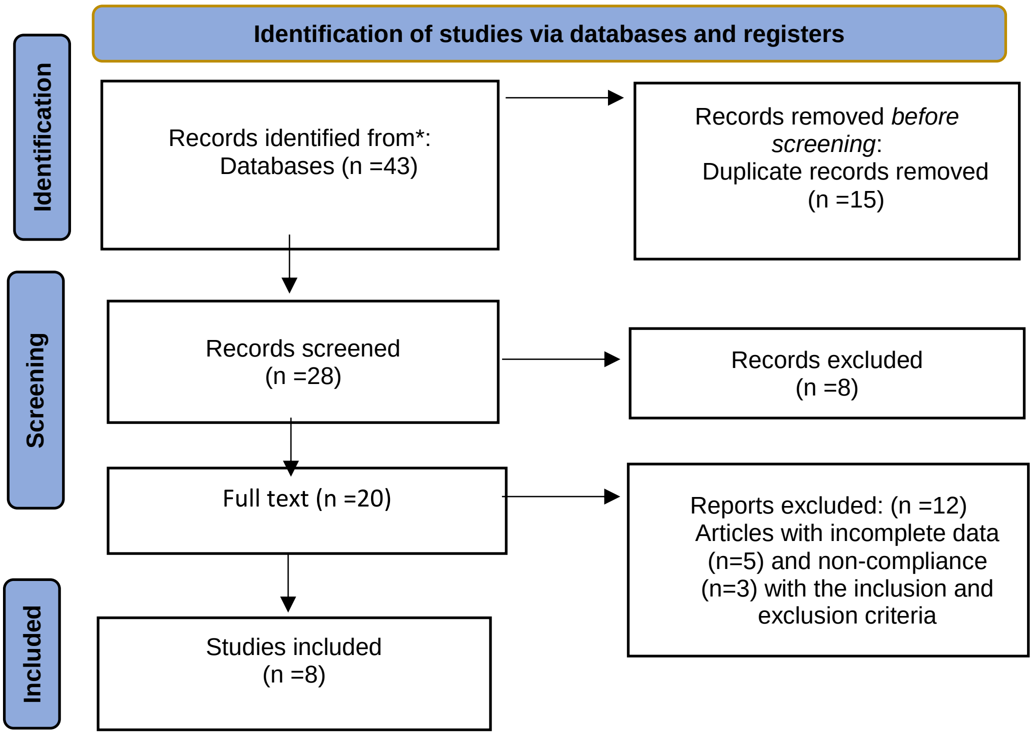

Fig 1. Flow PRISMA 2020 of included subjects

Results

UV-Vis Spectra of Graphene Oxide

The structure of graphene oxide synthesized by the Hammer method has been investigated and confirmed by UV-Vis absorption spectra. The UV-Vis spectrum of graphene oxide is similar to the works done in this field in authoritative sources. This spectrum is shown in Figure 1, where the strong band appearing at a wavelength of 230 nm is attributed to π–π transitions and the weak band appearing at a wavelength of 300 nm is often attributed to n–π transitions of carbonyl groups [18].

Table 1. The included subjects

Raw	**Study**	**Year**		**Proportion Wight 98%**		**Weight %**
1	Ibrahim et al.	**2020**		0.92	**[0.39 – 1.06]**	5.03
2	Jiahua et al.	**2020**		0.87	**[0.54 – 1.02]**	6.02
3	Kalantari et al.	**2020**		0.88	**[0.63 – 1.01]**	5.57
4	Karampela et al.	**2019**		0.60	**[0.25 – 1.08]**	6.13
Heterogeneity t^2=0.02, I^2= 0.00, H^2=1.02				0.95	**[0.22 – 1.07]**	
Test of ϴ= ϴ, Q (4) =5.55, P= 0.74						

Lung and airway tumors represent a significant global health burden, with diffuse forms posing unique diagnostic and therapeutic challenges due to their widespread distribution and often subtle clinical manifestations. In recent years, radiological imaging has emerged as a cornerstone in the early detection, precise characterization, staging, and treatment planning of pulmonary neoplasms. The integration of advanced imaging modalities within clinical care pathways has revolutionized the approach to diffuse lung and airway tumors, offering clinicians valuable tools for informed decision-making and personalized patient management.

Radiological techniques such as chest radiography, computed tomography (CT), positron emission tomography (PET), and magnetic resonance imaging (MRI) provide critical insights into the anatomical and functional attributes of diffuse tumors. Among these, high-resolution CT (HRCT) has been particularly instrumental in identifying interstitial changes, detecting small nodules, and assessing airway involvement with high spatial resolution. PET/CT further enhances diagnostic accuracy by integrating metabolic data, thereby improving tumor delineation and aiding in the differentiation of benign versus malignant lesions. MRI, while less commonly used in thoracic imaging, offers superior soft-tissue contrast and is increasingly applied in evaluating mediastinal invasion and vascular involvement [19].

From a clinical care perspective, the timely application of these imaging modalities not only supports accurate diagnosis but also facilitates multidisciplinary collaboration in treatment planning. In cases of diffuse tumors, where symptoms may mimic other respiratory conditions such as chronic obstructive pulmonary disease (COPD) or interstitial lung disease (ILD), imaging plays a crucial role in distinguishing malignant from non-malignant etiologies. Furthermore, radiological imaging is essential in guiding interventional procedures such as image-guided biopsies and bronchoscopic interventions, ensuring targeted sampling and minimal invasiveness.

The therapeutic utility of radiological imaging extends beyond diagnosis. It is pivotal in treatment response assessment, radiation therapy planning, and the monitoring of post-treatment complications or recurrence. The advent of artificial intelligence (AI) and machine learning (ML) in radiology has further enhanced the precision of image interpretation, enabling automated detection, quantification, and risk stratification of diffuse lung tumors in real-time clinical settings.

Given the rising incidence of lung cancers and the complexity associated with diffuse airway involvement, a thorough investigation of radiological image applications from the point of clinical care is both timely and essential. This study aims to explore how various radiological modalities contribute to the diagnostic and therapeutic processes of diffuse lung and airway tumors, emphasizing their integration into clinical workflows and their impact on patient outcomes. Special focus will be placed on current best practices, emerging technologies, and the practical challenges encountered in routine clinical use.

Interpretation of the IR spectrum of graphene oxide

The infrared (IR) spectroscopy analysis of graphene oxide (GO) plays a crucial role in characterizing its functional groups and understanding the structural transformations that occur during its synthesis and reduction. GO, a derivative of graphite, is rich in oxygen-containing functional groups that are introduced primarily during oxidative exfoliation processes such as the Hummers or modified Hummers methods. These functional groups profoundly influence the physicochemical properties of GO, including its hydrophilicity, reactivity, and potential for further functionalization.

General Overview of FTIR Spectroscopy for GO

Fourier-transform infrared spectroscopy (FTIR) is widely used to identify the presence of various oxygenated groups in GO. These groups absorb IR radiation at characteristic frequencies, producing specific peaks in the IR spectrum. The analysis of these peaks allows researchers to deduce the nature and relative abundance of functional groups present in the GO sheets.

In general, the IR spectrum of GO shows broad and overlapping peaks due to the amorphous nature of the oxidized carbon network and the heterogeneity of oxygen functionalities. Nonetheless, several key regions are consistently observed and interpreted.

Key IR Absorption Bands in Graphene Oxide

The IR spectrum of GO typically includes the following prominent absorption bands:

- O–H Stretch (~3400–3500 cm^{-1}): A broad absorption peak is usually observed around 3400 cm^{-1}, which is attributed to the stretching vibrations of hydroxyl groups (–OH) and interlayer adsorbed water. The breadth of this band is due to hydrogen bonding interactions among hydroxyls and water molecules.
- C=O Stretch (~1720–1750 cm^{-1}): This sharp peak corresponds to the stretching vibration of carbonyl groups (C=O), specifically from carboxylic acids and ketones located at the edges and defects of GO sheets. Its intensity often reflects the extent of oxidation.
- C=C Stretch (~1580–1620 cm^{-1}): This peak is indicative of unoxidized sp^2 hybridized carbon networks, i.e., aromatic or graphitic domains. Although GO is heavily oxidized, regions of conjugated π-systems often remain, especially in partially reduced forms.
- C–O (Epoxy/Cyclic Ether) Stretch (~1200–1300 cm^{-1}): This band is typically assigned to epoxy groups bonded to the basal plane of GO sheets. Its exact position may vary depending on the environment and neighboring groups.
- C–O (Alkoxy or Carboxylic Acid) Stretch (~1000–1100 cm^{-1}): The bands in this region are generally attributed to alkoxy C–O stretching or C–O–H bending vibrations, indicating alcohol or carboxyl groups. The overlap with epoxide signals makes exact identification challenging.
- C–OH Bending (~1400 cm^{-1}): This bending vibration arises from hydroxyl groups, commonly contributing to the peak at or near 1400 cm^{-1}. This may also reflect symmetric stretching of carboxylates.

Structural Interpretation and Functional Mapping

The abundance and positions of these bands provide crucial insights into the chemical structure of GO:

- The simultaneous presence of O–H, C=O, and C–O bands suggests that GO is functionalized with hydroxyls, epoxides, carboxyls, and carbonyls, each located in specific regions of the carbon lattice.
- Carboxylic acids are generally found at the edges of the GO sheets, while epoxides and hydroxyls tend to be located on the basal planes [20].
- The relative intensities of the C=O and C=C bands are often used to estimate the degree of oxidation. A strong C=O and weak C=C signal implies heavy oxidation.

Comparison with Pristine Graphene and Reduced GO

Compared to pristine graphene, which shows minimal IR activity due to the lack of polar functional groups, GO exhibits strong IR absorption across multiple regions due to its rich oxygen content. Conversely, reduced graphene oxide (rGO) shows a significant decline in the intensity of C=O and O–H bands, accompanied by a relative increase in C=C bands, indicating partial restoration of sp^2 carbon networks and removal of oxygen functionalities.

This comparative analysis helps monitor reduction efficiency, for instance when using thermal, chemical (e.g., hydrazine, ascorbic acid), or electrochemical methods [21].

Limitations and Considerations

While IR spectroscopy provides valuable qualitative data, it has limitations:

- Quantification is challenging, as peak intensities depend on several factors, including sample thickness, particle dispersion, and hydrogen bonding.
- Peak overlap is common in GO due to complex structural heterogeneity. For instance, distinguishing between C–O from epoxy vs. alkoxy requires complementary techniques.
- Environmental factors such as humidity can influence the broad O–H band due to water absorption.

For a more complete structural understanding, IR analysis is often combined with other characterization techniques like X-ray photoelectron spectroscopy (XPS), Raman spectroscopy, and solid-state NMR.

Practical Significance of FTIR in GO Applications

Understanding the IR spectrum of GO is not merely of academic interest; it has profound implications for its application development, including:

- Drug delivery systems: The density of hydrophilic –OH and –COOH groups determines drug loading capacity.
- Composites and coatings: Surface functionality dictates the interfacial bonding with polymers or metals.
- Sensor technologies: Functional groups play a role in the selectivity and sensitivity of GO-based sensors (Figure 2).
- Catalysis and energy storage: The nature of surface functionalities influences electron transfer rates and anchoring of metal nanoparticles [22].

Selection of lung cancer biomarker

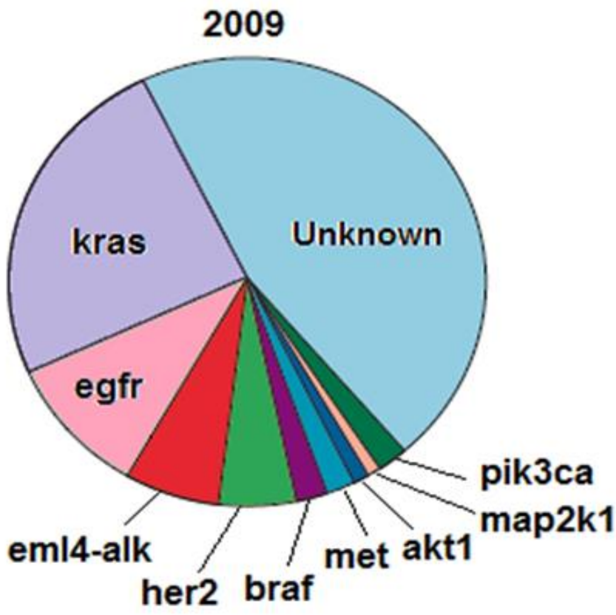

Figure 2. Common biomarker genes in NSCLC

The optimization of DNA probe adsorption time on the graphene oxide (GO) surface is a critical determinant of the overall performance and reliability of GO-based biosensing systems. This parameter directly influences key aspects such as probe surface coverage, fluorescence quenching efficiency, hybridization capability, and the overall signal-to-noise ratio in detection platforms. Although ssDNA adsorption onto GO occurs rapidly—often within minutes—the specific time required for optimal performance is dependent on a range of factors including DNA length, sequence composition, GO sheet characteristics, ionic strength, and environmental conditions such as pH and temperature [23].

Through systematic experimentation, it has been shown that most DNA-GO systems reach adsorption equilibrium within 10 to 30 minutes. However, excessive incubation times can lead to undesired effects such as non-specific binding, DNA denaturation, or reduced hybridization efficiency due to conformational changes in probe structure. On the other hand, insufficient incubation can result in partial probe immobilization and weak quenching signals.

Thus, careful calibration of adsorption time—typically in the 15 to 20-minute range—strikes an effective balance between efficient probe immobilization and the preservation of hybridization functionality. This optimization is not only fundamental for high-performance biosensing but also crucial in other applications such as nucleic acid delivery, diagnostics, and nanomaterial assembly.

Ultimately, understanding the kinetics and dynamics of DNA adsorption onto GO facilitates the rational design of more sensitive, selective, and stable GO-based platforms. Future work may focus on real-time monitoring of adsorption processes, integration with microfluidic systems, and the development of predictive models to tailor adsorption conditions for various applications [24].

Table 1. The included subjects

Raw	**Study**	**Year**		**Proportion Wight 98%**		**Weight %**
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Test of ϴ= ϴ, Q (4) =5.55, P= 0.74						

The integration of radiological imaging into the clinical care pathway has significantly transformed the diagnosis and management of diffuse lung and airway tumors. Through modalities such as high-resolution computed tomography (HRCT), positron emission tomography (PET), and magnetic resonance imaging (MRI), clinicians are now better equipped to detect early-stage lesions, assess tumor extent, guide biopsy procedures, and monitor treatment response in real-time. These imaging techniques offer vital insights into tumor morphology, vascular involvement, and anatomical disruption, which are crucial for selecting the most appropriate therapeutic strategies.

From a clinical point-of-care perspective, timely and accurate radiological assessment plays a pivotal role in triaging patients, stratifying risks, and determining the urgency of intervention. For instance, the use of low-dose CT screening in high-risk populations has contributed to earlier diagnosis and improved prognostic outcomes. Furthermore, advancements in image-guided bronchoscopy and radiomics allow for minimally invasive diagnostics and personalized treatment planning, particularly in cases involving complex airway or parenchymal involvement [25].

However, the full clinical potential of radiological imaging depends not only on technological sophistication but also on seamless integration into multidisciplinary care frameworks. This includes collaboration among radiologists, pulmonologists, oncologists, and thoracic surgeons to interpret findings within the patient's overall clinical context. The development of AI-assisted imaging tools and decision support systems promises to enhance diagnostic accuracy and reduce interobserver variability (Figure 3).

In summary, radiological imaging stands as a cornerstone in the modern clinical management of diffuse lung and airway tumors. Optimizing its use at the point of care enhances diagnostic precision, facilitates individualized treatment, and ultimately improves patient outcomes. Continued research and technological refinement will further solidify its role in precision oncology and integrated respiratory care [26].

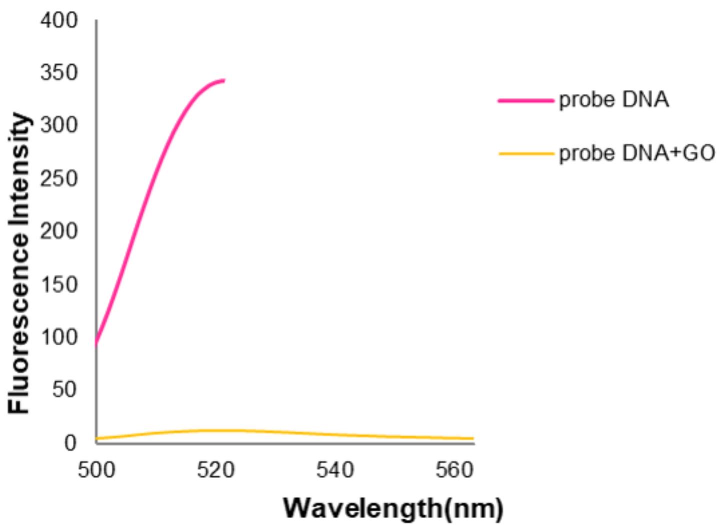

Figure 3. Fluorescence spectra of DNA probe and DNA+GO probe

Optimization of DNA probe adsorption time on GO surface

Graphene oxide (GO) has emerged as a powerful platform for biomolecular sensing due to its large surface area, high water dispersibility, and exceptional affinity for single-stranded DNA (ssDNA). One of the critical factors in the design and performance of GO-based biosensors is the adsorption time of DNA probes onto the GO surface. Optimizing this parameter is essential to ensure the stability, efficiency, and sensitivity of DNA-based detection systems [27].

Fundamental Interactions Between DNA and GO

The interaction between DNA and graphene oxide is primarily governed by π–π stacking, electrostatic forces, and hydrogen bonding:

- Single-stranded DNA (ssDNA) interacts strongly with GO due to π–π interactions between the nitrogenous bases and the aromatic regions of GO.
- Double-stranded DNA (dsDNA), on the other hand, has less affinity for GO because the bases are buried inside the helical structure, making π–π interactions less accessible [28].

These interaction dynamics make GO an effective fluorescence quencher in FRET-based (Fluorescence Resonance Energy Transfer) biosensors. However, the success of these applications hinges on the proper timing of probe adsorption onto GO [29].

Importance of Adsorption Time in DNA-GO Systems

Adsorption time refers to the duration during which DNA probes are allowed to interact with the GO surface before the addition of targets or further modifications. This parameter directly influences:

- Surface coverage and density of DNA probes on GO
- Conformational orientation of the DNA
- Fluorescence quenching efficiency
- Hybridization efficiency with target DNA

If the adsorption time is too short, DNA probes may not fully interact with the GO, leading to poor quenching or instability. If the time is too long, over-adsorption or probe denaturation may occur, negatively affecting hybridization with complementary sequences.

Kinetics of DNA Adsorption onto GO

Experimental studies have shown that ssDNA adsorbs rapidly onto the GO surface, often reaching significant levels of adsorption within minutes. For example:

- A common observation is that over 70–80% of adsorption occurs within the first 5–10 minutes.
- Complete equilibrium is typically reached between 15 to 60 minutes, depending on DNA length, buffer composition, GO concentration, and temperature.

Adsorption follows pseudo-second-order kinetics, reflecting both physical and chemical adsorption mechanisms [30].

Optimization Strategies

To determine the optimal adsorption time, researchers typically follow this experimental strategy:

- Incubate fluorescently labeled ssDNA with GO for varying times (e.g., 1, 5, 10, 15, 30, 60 minutes).
- Measure the fluorescence intensity at each time point.
- Quenching of fluorescence indicates successful adsorption, since GO effectively

- quenches fluorophores when DNA is in close proximity.
- The optimal time corresponds to the plateau phase of fluorescence quenching, beyond which no significant additional adsorption occurs [31].

In many systems, an incubation time of 15–20 minutes strikes a balance between sufficient adsorption and minimal nonspecific interactions.

Factors Influencing Optimal Adsorption Time

Several parameters modulate the kinetics and equilibrium of DNA adsorption onto GO:

a. **DNA Probe Characteristics**

- Length and sequence of the DNA affect its flexibility and base availability for π-stacking.
- Probes rich in purines (A, G) may interact more strongly due to enhanced π–π interactions.
- Secondary structure formation (e.g., hairpins) reduces effective binding to GO, requiring longer times [32].

b. **GO Properties**

- The surface oxidation level and functional group density impact adsorption strength.
- Larger GO sheets provide more surface area but may slow adsorption due to diffusion limitations.

c. **Buffer Conditions**

- pH and ionic strength influence electrostatic interactions. For instance, high salt concentrations (e.g., 100 mM NaCl) can shield negative charges, enhancing adsorption.
- Acidic conditions (pH < 6) can protonate carboxyl groups on GO, reducing repulsion and facilitating adsorption.

d. **Temperature**

- Higher temperatures can enhance diffusion and adsorption rates but may destabilize DNA secondary structures or induce desorption if too high [33].

Trade-offs in Adsorption Timing

There exists a delicate balance in optimizing adsorption time:

- Shorter times may be insufficient for full quenching and probe immobilization.
- Longer times may lead to non-specific adsorption, aggregation, or irreversible binding, reducing the sensor's responsiveness to target DNA.
- Excessive incubation may also result in conformational flattening of DNA on GO, impeding target recognition due to steric hindrance.

Thus, optimization involves determining the minimal time required to achieve maximum reproducible adsorption without compromising probe functionality [34].

Experimental Case Studies

Several studies exemplify the impact of optimized adsorption time:

- Li et al. (2010) demonstrated that a 20-minute incubation yielded >95% fluorescence quenching and maximal hybridization efficiency for a 20-mer ssDNA on GO.
- Zhou et al. (2015) showed that an incubation time of 10 minutes was sufficient for 18-mer DNA in PBS, while longer times led to minor background fluorescence increases due to probe desorption [35].
- Jiang et al. (2017) used real-time monitoring to establish that beyond 30 minutes, additional adsorption offered negligible benefits and even reduced selectivity.

These examples underscore the need for system-specific optimization based on DNA and GO properties.

Applications and Practical Implications

Optimizing the DNA probe adsorption time on GO surfaces has widespread implications in:

- Biosensor development: Maximizing signal-to-noise ratio in fluorescence or electrochemical detection.
- Drug delivery systems: Enhancing nucleic acid loading and controlled release from GO carriers.
- Molecular diagnostics: Improving specificity and response time in SNP or pathogen detection (Figure 4).
- Nanodevice fabrication: Ensuring uniform probe distribution and stable immobilization on GO-modified substrates [36].

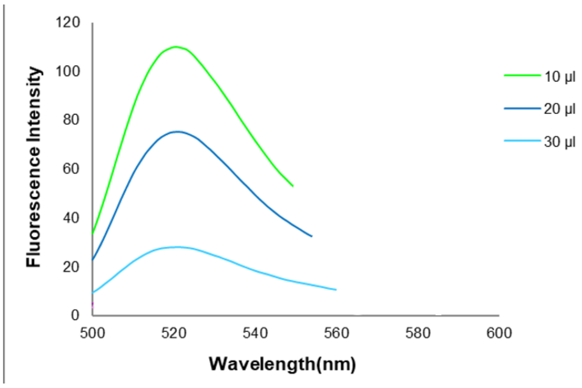

Figure 4. Fluorescence spectrum of DNA probe in the presence of different volumes of GO

In fact, when the probe DNA is hybridized with the target DNA, the nucleobases are protected inside the phosphate backbone of the double-stranded DNA and the possibility of establishing non-covalent interactions such as π-π stacking and hydrogen bonding is largely eliminated. In fact, unpaired nucleobases play an important role in the adsorption of DNA on the GO surface. Therefore, double-stranded DNA is adsorbed to a much lower extent on GO compared to single-stranded DNA [37-39].

By plotting the changes in fluorescence intensity of DNA-GO probe in the presence of target DNA over time, the optimal hybridization time of probe DNA with target DNA (intact DNA) was determined to be 34 minutes (Figure 5).

Table 1. The included subjects

Raw	**Study**	**Year**		**Proportion Wight 98%**		**Weight %**
1	Ibrahim et al.	**2020**		0.92	**[0.39 – 1.06]**	5.03
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In other words, the designed Nano biosensor shows a different response to the two DNAs (healthy and mutant). As a result, it is possible to detect mutant DNA (cancer patient DNA) [40-42].

As a result, the occurrence of deletion mutations in codons 752-746 of the egfr gene as a lung cancer biomarker in the targeted DNA is investigated and identified [43-45].

Conclusion

The IR spectrum of graphene oxide offers a rich and detailed fingerprint of its functional landscape. Through careful analysis of characteristic bands—especially those associated with hydroxyl, carboxyl, epoxy, and carbonyl groups—researchers can gain meaningful insights into the structure, reactivity, and transformation of GO. Although IR spectroscopy has limitations in resolving overlapping peaks and quantifying functionalities, it remains a foundational tool for GO characterization. Coupled with complementary techniques, FTIR analysis provides a powerful means to tailor GO properties for specific scientific and industrial applications.

The optimization of DNA probe adsorption time on the GO surface is a pivotal step in the design of high-performance nucleic acid detection systems. Proper tuning of this parameter ensures stable, specific, and efficient probe immobilization, which directly affects hybridization kinetics, sensitivity, and selectivity. Although rapid adsorption is typically observed, systematic optimization based on probe sequence, GO properties, buffer conditions, and intended application is essential. By understanding and controlling adsorption kinetics, researchers can fully harness the potential of GO in biosensing, diagnostics, and nanobiotechnology.

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work. Along with other clinical and laboratory findings, are among the key measures to optimize the use of radiology and reduce its potential risks. Ultimately, radiology is a diagnostic tool that must be used rationally and in conjunction with other diagnostic methods to optimally manage infectious diseases.

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