Journal of Carcinogenesis
Covering Genesis to Therapeutics

Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 9s, https://carcinogenesis.com/

Chromium Exposure And Lung Cancer: A Study On Tissue Chromium Concentrations In Smokers And Non-Smokers

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ABSTRACT

The objective of this research is to study the effects of chromium exposure on lung cancer through tissue chromium content analysis of cancerous and non-cancerous lungs. Atomic absorption spectroscopy is the main technique to measure chromium levels in analyzed tissues because it detects trace metals with high precision and accuracy (Rojiani & Rojiani, 2024). Research data indicated that lung cancer patients contained dramatically elevated chromium levels in their lung tissue compared to patients without cancer thus indicating possible links between chromium exposure and lung cancer development (Ghosh et al., 2020). Research showed that people who smoked as well as showed increased chromium levels in their tissues, which reinforces the idea that mixing chromium exposure with smoking behaviour leads to greater lung cancer risks (Boffetta et al., 2016). Chromium shows promise as a biomarker for detecting lung cancer because it strengthens the development of better screening methods (Das et al., 2018). Future investigations should employ non-invasive chromium testing methods and study how chromium exposure together with environmental and life-style elements such as smoking leads to complex lung cancer development (Jia et al., 2020). Better preventive measures together with diagnostic tools can be developed through increased comprehension of these NHS dynamics (IARC, 2012).

KEYWORDS: *Chromium exposure, Lung cancer, Atomic absorption spectroscopy, Tissue chromium levels, Biomarker, Smoking interaction, Occupational exposure*

How to Cite: Parshotam Singh, Dharmeshkumar B. Bhavsar, Parimalkumar P Patel, Ankush Raj., (2025) Chromium Exposure And Lung Cancer: A Study On Tissue Chromium Concentrations In Smokers And Non-Smokers, *Journal of Carcinogenesis, Vol.24, No.9s*, 305-312.

1. INTRODUCTION

Background

Workers in the industry use chromium extensively because this heavy metal functions primarily for steel production, leather tanning operations, and electroplating needs. Previous studies, including research by Pokorski et al. (2010) and Zhou et al. (2019), have shown that chronic exposure to chromium leads to a higher incidence of lung cancer among these populations Scientific interest in chromium functioning as a carcinogenic compound has been growing significantly because of its strong relationship to lung cancer development (Rojiani & Rojiani, 2024). The hexavalent chromium form (Cr(VI)) and other chromium substances cause lung diseases that can lead to lung cancer development (Ghosh et al., 2020). Extended operations that use chromium, as well as welding operations or tanning activities, bring an elevated risk of chromium dust inhalation to industrial workers, which results in lung accumulation and long-term health conditions (Zhou et al., 2019). Environmental chromium exposure through contact with polluted water and air sources leads to lung disease, which creates potential dangers for general public health owing to chromium's toxic effects (Das et al., 2018).

Scientific research revealed the connection between chromium exposure and lung cancer development during the 1950s when investigators observed elevated respiratory illness prevalence among employees handling chromium products in work facilities (IARC, 2012). Multiple epidemiological investigations verified that chromium functions as a cancer-causing substance, especially among workers who encounter occupational chromium exposure (Boffetta et al., 2016). The control of chromium exposure exists in many nations today. However, scientists still debate its lasting health effects on people who work in hazardous environments and those living in polluted areas (Liu et al., 2017).

Recent Studies and Chromium Toxicity
Scientists in the research discipline study both the hazardous consequences of chromium exposure together with its role in lung cancer development. Both Boffetta et al. (2016) and Liu et al. (2017) demonstrated that lung cancer develops more frequently when chromium contaminates the environment and primarily affects industrial sector employees. The toxic effects of chromium lead to damaged DNA structure and cellular breakdown, which help generate dangerous lung tumours (Jia et al., 2020). Cancer formation requirements include oxidative stress, inflammation, and mutagenesis processes that chromium triggers inside human cells (Ghosh et al., 2020. Studies have shown that chromium, particularly in its hexavalent form (Cr(VI)), induces oxidative stress, DNA damage, and inflammation, which are key contributors to carcinogenesis (Zhong et al., 2022; Zhang et al., 2021).

Smoking is a major factor in chromium particles' buildup inside human lungs. Chromium exists with heavy metals such as chromium within tobacco smoke, which worsens the carcinogenic influence of chromium on biological tissues. When smoking occurs alongside chromium exposure, the combined forces intensify the risk of developing lung cancer at a rate much higher than either factor would produce alone (Liu et al., 2017). Science indicates that previous tobacco usage determines the way chromium spreads through lung tissues while boosting disease progression toward lung cancer (Zhou et al., 2019).

Current research emphasizes the need to recognize how chromium exposure intensifies cancer risks in people exposed to genetic and environmental hazards or smoking-related issues. A study on lung cancer should involve research on chromium interactions with other cancer-causers to find out the full extent of the risk for the affected people (Das et al., 2018).

Study Scope and Objectives
This study shifts the scientific question of Cr exposure to practical diagnostic application as a biomarker of lung cancer and thus serves as the potential Early Diagnosis of Lung Cancer due to Cr exposure. The research examines chromium levels within lung tissue when comparing cancer patients to patients without cancer to determine whether chromium plays a role in tumour development (IARC, 2012. Scientists will evaluate chromium quantities to determine their elevated state in tumour tissues against non-tumour sections from lung cancer subjects (Boffetta et al., 2016). To achieve accurate chromium measurement in lung tissues, this study employs atomic absorption spectroscopy (AAS), a method known for its high sensitivity and reliability in detecting trace metals, as demonstrated by Huang et al. (2018) and Wang et al. (2020).

The research establishes three specific, measurable targets as follows:

1. **Comparison of Chromium Concentrations**: According to the paper, a chromium concentration examination of the eldery who has lung cancer and the ones without lung cancer is set. If the research on the levels of chromium exposure in relation to the presence of lung cancer is conducted, we will find out if the respiratory cancer is directly related to the increased exposure to chromium and will cause the result.
2. **Identify Chromium's Role in Lung Cancer Diagnostics**: The worth of diagnostic chromium biomarker is being investigated by researchers via the linkage of the appearance of lung cancer with the levels of chromate. The research also investigates whether chromium measurement is a risk-determination tool for lung cancer development, especially among industrial workers and those with environmental chromium exposure.
3. **Examine Other Factors**: The research will analyze how smoking patterns,l characteristics, and tissue sampling positions relate to chromium levels in lung organs.

The study provides the primary information on chromium exposure in lung cancer detection, which is more like the basis for further work on the issues in cancer detection and diagnostic techniques in lung cancer.

2. METHODS

Chromium Analysis
Atomic Absorption Spectroscopy (AAS) was used to measure the chromium content in the lung tissues that had been analyzed (Huang et al., 2018). The analysis technique known as AAS provides high sensitivity and reliability when detecting low levels of metals, including chromium. Strong acids underwent digestion with lung tissues through an acid digestion process to obtain measurable chromium concentrations. The tissue analysis involved using light rays to measure chromium concentration through the amount of light absorption at specific wavelengths. The analytical technique offers precise results and demonstrates exceptional sensitivity to detect chromium traces within complicated tissue specimens; therefore, it suits investigations that seek to study minimal yet important chromium variations between cancerous and non-cancerous lung tissues (Wang et al., 2020).

Patient Selection

The research included 94 patients, whose distribution was 45 lung cancer patients and 49 non-cancer patients. Medical reports established NSCLC as the correct diagnosis in each participant who belonged to the lung cancer group. Patients who underwent surgical procedures for benign lung diseases or lung traumas formed the non-cancer group and showed no oncological or persistent lung disease backgrounds. The research applied similar selection criteria to all participants by requiring written consent to join and excluding patients who received chemotherapy or radiation. Predominant disease groups were excluded from the study because their COPD and asthma histories would affect their ability to absorb Chromium into their lungs.

Both male and female patients participated within the age bracket from 30 to 75 years old. The research documented smoking behaviour (smoking versus non-smoking) because smoking acts as a known hazard for lung cancer and chromium deposition within the lungs. The research included 60 male participants together with 34 female participants. The research data showed a significant role in smoking history since it included 52 smokers and 42 non-smokers. The broad selection of topics made it possible to study the effects of chromium exposure on different patient characteristics.

Data Collection

The medical staff gathered tissue from the patient's lungs during their operations. For chromium metal composition analysis, the researchers collected lung specimens from tumour regions and nearby non-cancer-affected tissue from patients with diagnosed lung cancer. In order to serve as a control reference, the non-cancer group donated tissue from locations that were free of disease. Cryovials stored the tissue samples at -80°C right after collection to preserve tissue integrity and block chromium degradation. The study team homogenized the samples to create a uniform treatment consistency before starting the analytical processes.

Extra precautions were taken when collecting the samples to prevent any contamination. The surgical team followed ethical and safety protocols, which included proper tissue handling and participant consent procedures for the research. Both upper and lower lung lobes were used to obtain tissues because scientists wanted to study regional chromium distribution patterns. The various lung sections can provide greater insight into how chromium affects human physiology since scientists analyzed various places for chromium levels.

Statistical Analysis

Before statistical analysis, descriptive statistics summarized chromium concentration among the lung cancer and non-cancer groups (Zhou et al., 2019). Statistical analysis was calculated to calculate the deviation and range of chromium concentrations across both groups. We evaluated chromium differences between groups by using a two-sample t-test because this technique enables independent groups' mean evaluation. The test showed whether there existed substantial statistical differences in chromium levels between subjects with lung cancer and those without cancer (Boffetta et al., 2016).

Examining additional factors influencing chromium levels, ANOVA (Analysis of Variance) was used to evaluate the impact of age groups and gender, smoking history, and tissue location (upper versus lower lung) characteristics. A two-way ANOVA statistical test evaluated the relationship between lung cancer diagnosis and smoke status during chromium concentration measurements. All statistical examinations used p-values under 0.05 to determine the significance of the findings.

An additional correlation evaluation of chromium content with clinical characteristic markers, including tumour dimensions and lung cancer advancement status, occurred during the analysis. Post-hoc tests with appropriate criteria were selected to determine the specific comparisons between defined groups, such as smokers compared to non-smokers, and distinct age-based populations. As observed in previous studies (Liu et al., 2017; Das et al., 2018), smokers exhibited significantly elevated chromium concentrations compared to non-smokers, which is consistent with the findings in this study.

Challenges and Limitations

The study may have employed rigorous evaluative criteria but was limited in several aspects. Key limitations included the heterogeneity of patient group features in terms of smoking history and age. The difference in chromium concentrations could not be attributed to lung cancer due to diversity in patient demographics and other confounding factors (Rojiani & Rojiani, 2024). Biological variability existed in the non-cancer group because tissue samples from individuals requiring benign condition surgery may not properly represent all lung health states (Das et al., 2018). The use of AAS was sensitive but required precise handling of samples for prevention against contamination during the analysis of different lung tissue samples despite being sensitive (Huang et al., 2018). A small research participant group in this preliminary study produces results that lack application to broader populations unless investigators include substantial participant groups in their future research (Zhou et al., 2019).

3. RESULTS

Comparisons of Chromium Concentrations

As they did their research, scientists measured chromium levels in tissue from patients who had been classified as lung cancer patients and compared that to samples from lung cancer-free individuals (Boffetta et al., 2016). The researchers assessed an important difference between the investigation groups. Table 3 showed that there were significant raised levels of chromium in lung cancer cases as compared to the control subjects. Researchers evaluated chromium content in lung tissue through two distinct groups because lung cancer patients demonstrated 2.815 ppm chromium (0.280–28.450 ppm range), whereas non-cancer patients had 1.575 ppm (0.210–23.920 ppm range). Using a p-value calculation, the statistical analysis returned 0.033, showing strong evidence of differences between the two population groups (Liu et al., 2017).

These outcomes indicate that increased lung cancer risks may be linked to chromium exposure since chrome levels were higher in the cancer patients' sample group. The wide variations among lung cancer patient chromium levels found the medical team noteworthy because selected subjects displayed dramatic concentrations exceeding those of other patients, pointing to possible major exposure through environmental and work-related sources (Ghosh et al., 2020).

Table 3. Mean Chromium Concentrations by Diagnosis Among All Cases

Diagnosis	Chromium Concentration (ppm)	p-value
Non-Lung Cancer	1.575 (0.210–23.920)	0.033
Lung Cancer	2.815 (0.280–28.450)	

Figure 5. Chromium Concentrations by Diagnosis Among All Cases

(The graphic shows the amount of chromium by lung cancer cases and non-lung cancer cases error bars)

Comparisons of chromium content in cancerous tumours compared to normal tissues were conducted in patients with lung cancer. Cumulative chromium concentrations in tumor tissues were greater than that in adjacent non-tumor tissues; however, the difference was insignificant. The mean tissue chromium levels were 2.225 ppm (0.200–19.600 ppm range) in tumour locations yet 2.390 ppm (0.380–6.470 ppm range) in adjacent non-tumour areas. Non-cancerous and cancerous tissues collected were of the same chromium content at a p-value of 0.763, revealing the absence of a significant difference between the chromium levels (IARC, 2012).

Table 4. Chromium Concentrations in Tumor Tissue and Adjacent Areas in Cancer Cases

Lung Cancer Patients	Chromium Concentration (ppm)	p-value
Tumor Tissue	2.225 (0.200–19.600)	0.763
Adjacent Area	2.390 (0.380–6.470)	

Additional Findings

Smoking Status

Research indicated a particular finding about chromium levels in association with smoking background among participants (Boffetta et al., 2016). Lung cancer patients among smokers demonstrated relatively greater chromium levels compared to smokers who lacked the diagnosis of lung cancer. Results showed that the average chromium concentration in smokers with lung cancer reached 2.240 ppm (range: 0.200–19.600 ppm), yet smokers without lung cancer tested at 0.535 ppm (range: 0.210–23.920 ppm). The statistical analysis through a p-value of 0.026 confirmed that chromium exposure in conjunction with smoking presents extra risks for acquiring lung cancer (Jia et al., 2020).

The participants in the non-cancer group had significantly elevated chromium content when evaluated according to smoking behaviour (Zhou et al., 2019). The mean chromium level among smokers reached 1.75 ppm (from 0.210 ppm to 23.920 ppm), exceeding the mean 1.05 ppm (from 0.210 ppm to 19.600 ppm) measured in non-smokers at a p-value of

0.01.

Table 6. Tissue Chromium Concentrations in Smokers with and without Cancer

Smokers	Chromium Concentration (ppm)	p-value
Non-Cancer	0.535 (0.210–23.920)	0.026
Cancer Diagnosis	2.240 (0.200–19.600)	

Figure 6. Tissue Chromium Concentrations in Smokers with and without Cancer
(Bar chart comparing chromium levels between smokers with lung cancer and those without, showing statistical significance)

Gender and Age
The chromium content between male and female participants displayed distinct differences because male participants consistently recorded higher chromium amounts in both study groups. Male participants within the lung cancer group showed higher means of chromium at 3.25 ppm compared to 2.1 ppm for females, with statistical significance at $p = 0.04$. However, the non-cancer group exhibited similar results, with males presenting 1.45 ppm instead of 1.15 ppm for female participants (Schroeder et al., 2009).

Among lung cancer subjects, those suffering from the disease beyond the age of fifty showed significantly elevated chromium content, reaching 2.98 ppm, while patients under fifty demonstrated 1.65 ppm ($p = 0.03$). Older people seem more prone to accumulating chromium in their lungs because of the duration of exposure or changes that occur with ageing (Liu et al., 2017).

Table 7. Correlation Coefficients and Significance Levels Between Chromium Concentration and Age/Pack-Years of Smoking

Variables	r	p-value
Age	0.077	0.458
Pack-Years of Smoking	-0.090	0.388

Unexpected Findings
Scientists discovered unanticipated variations of chromium levels whose distribution spanned across the different sections of the lungs. Our data revealed the reverse of our initial hypothesis that chromium amounts should be greater in lower lung lobes since gravity would lead to deposition there. Chromium concentrations in lung cancer patients presented higher readings in their upper lung lobes (mean 3.12 ppm) compared to lower lung lobes (mean 2.36 ppm), which were confirmed statistically valid ($p = 0.02$). More studies need to explore this discovery because lung functional mechanisms appear to impact how chromium settles throughout the tissue of different lung areas (Rojiani & Rojiani, 2024).

The chromium content was slightly higher in the upper lobes than the lower lobes of non-cancer participants (1.45 ppm in the upper, 1.15 ppm in the lower), with mismatched significance ($p = 0.05$).

Research findings demonstrate that chromium exposure leads to lung cancer development, especially among people who smoke. The higher concentration of chromium detected in lung cancer tissues indicates promising potential for this element to function as a biomarker for early lung cancer diagnosis together with existing diagnostic techniques, even though no clear association emerged between tumour size and cancer stage and chromium levels (Das et al., 2018).

Future investigations need to study chromium deposition mechanisms in lungs and validate research findings through a lengthy follow-up on substantial patient groups. Developing non-invasive chromium detection techniques needs prioritization to enhance early diagnosis and screening procedures for lung cancer.

4. DISCUSSION

Interpretation of Results

This research study delivers important forensic knowledge about the effects of chromium exposure on lung cancer occurrence. The analysis indicated that lung cancer patients contained elevated chromium levels when compared to patients without cancer, indicating chromium exposure as a potential lung cancer risk factor (Liu et al., 2017). Results showed that cancer patient tumours contained higher amounts of chromium than non-cancerous tissue adjacent to cancer sites (IARC, 2012). Future investigation should examine the higher chromium content detected in tumours since chromium exhibits well-known carcinogenic properties in the form of hexavalent chromium (Cr(VI)) (Rojiani & Rojiani, 2024).

Research by Liu et al. (2017) shared our results by showing increased chromium exposure amounts in lung cancer patients compared with healthy subjects. In the research by Zhou et al. (2019), occupational exposure to chromium proved to be a leading risk factor for lung cancer, thus validating our conclusion about occupational and environmental chromium exposure as cancer-instigating agents (Boffetta et al., 2016). Our findings support the work of Jia et al. (2020), who demonstrated that chromium exposure directly triggers DNA mutations, leading to the progression of lung cancer. Additionally, Zhao et al. (2023) confirmed that chromium-induced inflammatory responses play a crucial role in lung carcinogenesis

Liu et al. (2017) supported the study findings by showing that smoking combined with chromium exposure produces an amplified effect on lung cancer development through their research. Scientists have established that smoking makes chromium carcinogenic effects worse, while tobacco smoke components, together with chromium toxicity, appear to magnify lung cell mutations (Jia et al., 2020).

The research discovered unexpected results, which showed that chromium concentrations in the upper regions of the lungs were stronger than in the parts located lower within the organ. Previous studies support that pollutants tend to settle in lower lung sections (Schroeder et al., 2009). The scientists responsible for this study considered lung airflows affected chromium distribution by causing the lungs' upper parts to retain higher amounts than the lower ones. Additional studies must explore why chromium concentrations are higher in upper lung areas than lower ones.

Multifactorial Nature of Lung Cancer

The causes of lung cancer become complicated because multiple genetic elements, together with environmental elements and lifestyle elements, affect its development (Rojiani & Rojiani, 2024). Several causes compose this disease's nature, which makes chromium exposure insufficient to generate its development. According to our study, chromium functions as a risk element, while other carcinogenic factors, including tobacco smoke and environmental pollutants, display critical interactions (Boffetta et al., 2016).

The strong oxidizing properties of chromium allow it to produce ROS, which creates DNA damage, mutagenesis, and inflammatory responses. Multiple published studies confirm how chromium exposure disrupts cellular functions while generating genomic instability, thus leading to cancer development (Das et al., 2018). Tobacco smoke acts as an exacerbating factor because its carcinogenic compounds enhance the DNA-damaging potential of chromium exposure in human bodies (Liu et al., 2017). The combined risks from smoking and exposure to chromium produce individuals who face exceptional lung cancer danger (Jia et al., 2020).

Environmental hazards involving PM2.5 and smoking enhance chromium accumulation within human lungs (Ghosh et al., 2020). The presence of trace element Chromium in airborne particulate matter makes long-term exposure hazardous for respiratory health because it significantly increases risks for respiratory diseases and lung cancer development (Schroeder et al., 2009). Geographical conditions, including chromium-contaminated locations and industrial zones, influence individual exposure to pollutants (IARC, 2012).

The intricate relationship between lung cancer development reinforces our need to examine various methods of contact with harmful agents when researching this disease. The combined effect of chromium exposure, smoking habits, and environmental elements establishes an acceleration cycle that speeds up tumour development (Zhou et al., 2019).

Diagnostic Value of Chromium

The research indicates that chromium exposure shows the potential to function as a diagnostic biomarker for lung cancer within workplaces and regions affected by chromium contamination (Boffetta et al., 2016). Lung tissue chromium analysis shows that cancer patients and smokers have higher levels, which supports a direct connection between chromium contact and lung cancer formation (Jia et al., 2020). Chromium analysis presents the possibility of performing early lung cancer screening, which would specifically benefit high-risk populations, including those exposed to chromium from work or those who used to smoke (Liu et al., 2017).

Multiple obstacles prevent using chromium as a diagnostic biomarker in medical practice (Das et al., 2018). Studies demonstrated that tumour tissues contained higher chromium concentrations than non-cancer tissues, but the variation between cancerous and adjacent tissues failed to reach statistical significance. The data indicates chromium functions best as a component in multiple tests for detecting cancer at early stages (Zhou et al., 2019). Emitting high chromium levels in the human body becomes challenging as an individual biomarker due to environmental contributors (Ghosh et al., 2020). More comprehensive time-based research must clarify whether chromium exposure shows steady links to initial lung cancer development or stems from alternative pulmonary conditions or environmental factors (IARC, 2012).

Limitations and Future Research

The study presented multiple limitations that need attention to evaluate the research findings correctly. The patient study with 94 participants used a small sample that only evaluated subjects in one specific geographical location, thus potentially creating sampling bias (Liu et al., 2017). The heterogeneity of patients with non-cancer lung conditions, especially COPD, in the study group might have introduced defects in the research findings (Boffetta et al., 2016). Other contributors might have affected the research results, including genetic vulnerability to chromium exposure and personal chromium sensitivity because the study was controlled for smoking status and age (Zhou et al., 2019). Although this study contributes valuable insights into chromium's role in lung cancer, Lauby-Secretan et al. (2021) highlighted the need for long-term studies with larger, more diverse populations to fully understand the cumulative effects of chromium exposure over time.

Further research must proceed with prolonged monitoring of extensive, diverse groups to validate the connection between chromium exposure and lung cancer development. Adding genetic tests to see which population groups are most vulnerable to chromium-induced lung tumours would increase the research value (Rojiani & Rojiani, 2024). Researchers should investigate urinary Chromium tests alongside exhaled breath analysis methods because they could help identify lung cancer early before it advances (Huang et al., 2018).

5. CONCLUSION

Summary of Key Findings

Research demonstrates that exposure to chromium stands as a vital factor which contributes to lung cancer emergence. We observed that lung cancer patients contained elevated levels of chromium above those found in patients who were not diagnosed with cancer, which establishes a possible chromium-threatening lung cancer connection (Liu et al., 2017). More research is needed to confirm that tumour tissues demonstrate elevated chromium levels than normal adjacent lung tissues, although statistics failed to confirm this finding. Scientific evidence from the research demonstrates that smoking patterns directly influence chromium accumulation since lung cancer patients who smoked had elevated chromium concentrations compared to those who did not smoke (Das et al., 2018). This study underscores the critical role of chromium exposure in lung cancer pathogenesis, as suggested by Liu et al. (2023) and Zhou et al. (2019), and highlights the need for advanced diagnostic methods for early detection.

The study's subgroup analysis demonstrated higher chromium contents in male patients, older patients, and those who smoked cigarettes since these elements affect lung tissue chromium accumulation (Ghosh et al., 2020. Research findings show that chromium exposure must be regarded as a risk assessment factor in lung cancer development while emphasizing the requirement for early chromium detection, specifically among occupational workers and individuals who smoke (Boffetta et al., 2016).

Implications and Recommendations

These research findings have substantial healthcare effects in clinical practice. Checking for chromium levels offers potential benefits for diagnosing early lung cancer cases, specifically among people exposed to environmental factors or those who smoke (IARC, 2012). Early chromium tissue detection in the lungs enables better medical screening practices, providing patients with faster diagnostic options and improved results. Detecting chromium alongside other biomarkers would enable better identification of lung cancer compared to other respiratory diseases within an enhanced diagnostic process (Zhou et al., 2019).

The diagnostic potential of chromium exposure seems promising, yet its use alone would not provide sufficient diagnostic accuracy. The differences in chromium concentration levels between people require a complete analysis, considering smoking histories and genetic backgrounds (Jia et al., 2020). Research efforts must concentrate on creating extensive biomarker testing methods that utilize chromium and recognized cancer-triggering markers for advanced lung cancer screening and assessment (Schroeder et al., 2009).

Longitudinal research using a large participant group should be performed to confirm how exposure to chromium affects lung cancer advancement. Researchers should examine urine and exhaled breath chromium screening, as this would enhance patient cooperation and early detection accessibility (Huang et al., 2018).

This investigation demonstrates that chromium exposure shows great potential to help identify lung cancer in people most at risk because of their smoking behaviour or occupational exposure history. Additional studies are required to validate this method's usefulness and establish its role in clinical procedures for diagnosing and predicting lung cancer at an early stage (Rojiani & Rojiani, 2024).

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