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SMOKING, ENVIRONMENTAL EXPOSURES, AND CHRONIC LUNG DISEASE AS KEY RISK FACTORS FOR LUNG CANCER IN NORTH SUMATRA

Background. Lung cancer remains the leading cause of cancer mortality worldwide, with increasing incidence in many developing countries. Understanding region-specific risk factors is essential for effective prevention strategies. This study **aimed** to identify major determinants of lung cancer in North Sumatra, Indonesia. **Materials and Methods.** A hospital-based observational study with a case–control analytical approach was conducted between August and November 2024 in three referral hospitals in North Sumatra. A total of 240 patients with histologically confirmed lung cancer and 240 controls without malignancy or chronic respiratory disease were included. Participants were comparable by sex and residential area, while age differences between groups were statistically adjusted in the multivariate regression model. **Results.** Smoking exposure differed significantly between cases and controls ($p = 0.023$). The multivariate analysis identified several independent predictors of lung cancer. Age <45 years increased the risk more than two-fold (OR 2.62; 95% CI 1.10—6.21), whereas age >65 years showed a lower relative risk (OR 0.54; 95% CI 0.33—0.88). The occupational exposure signicantly increased lung cancer risk (OR 1.91; 95% CI 1.13—3.25). Unhealthy indoor environments, characterized by poor ventilation and household pollutant exposure, were also associated with an increased risk (OR 2.53; 95% CI 1.45—4.40). Chronic respiratory diseases, particularly tuberculosis and chronic obstructive pulmonary disease, were more prevalent among cases and contributed to the elevated risk. **Conclusions.** Smoking exposure, occupational hazards, unhealthy indoor environments, and chronic pulmonary diseases are important determinants of lung cancer in North Sumatra. Public health strategies focusing on tobacco control, improved workplace safety, and reduction of indoor air pollution may substantially reduce lung cancer burden in this region.

Keywords: lung cancer, smoking, occupational exposure, indoor air pollution, tuberculosis.

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Lung cancer is one of the leading causes of cancer-related mortality worldwide, responsible for 2.2 million new cases and 1.8 million deaths in 2020 [1, 2]. It is classified into small cell lung cancer (SCLC) and non-small cell lung cancer (NSCLC), with adenocarcinoma as the most common subtype [1]. In Indonesia, lung cancer accounts for 8.6% of new cancer cases and 12.6% of cancer deaths, representing a major public health burden [3, 4].

Smoking remains the predominant risk factor, with smokers having up to ten-fold higher risk than non-smokers [5]. In Indonesia, nearly a quarter of the population are active smokers, with particularly high prevalence in North Sumatra [6]. Beyond tobacco, occupational and environmental exposures such as asbestos, radon, cadmium, and air pollutants significantly contribute to lung carcinogenesis, many of which are recognized as carcinogenic by the International Agency for Research on Cancer (IARC) [7—9].

Early initiation of smoking is strongly associated with increased lifetime nicotine dependence, higher daily cigarette consumption in adulthood, and prolonged exposure to carcinogenic substances found in tobacco smoke. These factors collectively heighten the risk of developing tobacco-related malignancies, including lung cancer, head and neck cancers, tracheobronchial tumors, and other smoking-associated diseases. Evidence consistently shows that individuals who start smoking at a young age face a substantially higher lifetime risk of cancer compared to those who initiate tobacco use later.

Chronic pulmonary diseases, including tuberculosis (TB) and chronic obstructive pulmonary disease (COPD), also increase lung cancer susceptibility through long-term inflammation and fibrosis [10—12]. Given the high mortality and multifactorial etiology of lung cancer, region-specific evidence is needed to guide prevention and early detection. This study therefore aimed to investigate the associations of smoking, environmental and occupational exposures, and chronic pulmonary diseases with lung cancer in the North Sumatra population.

Materials and Methods

Study design and setting. This study employed a hospital-based case–control design conducted between August and November 2024 at three tertiary referral hospitals in North Sumatra, Indonesia: Adam Malik Hospital, Universitas Sumatera Utara Hospital, and Santa Elisabeth Hospital. Cases and controls were recruited from the same hospitals to ensure that both groups originated from a comparable source population. Participants were comparable by sex and residential area, while age was treated as a potential confounding variable and adjusted statistically in the multivariate regression analysis.

Participants. The case group consisted of 240 patients with histologically confirmed lung cancer, including both SCLC and NSCLC, diagnosed based on histopathological examination supported by clinical evaluation.

The control group included 240 individuals without malignancy or chronic respiratory disease who were recruited from general outpatient clinics in the same hospitals during the study period. Controls were selected from patients visiting the clinics for non-respiratory and non-oncological conditions, ensuring that they represented the same underlying population as the cases.

Participants were eligible if they were ≥ 18 years old and willing to participate in the study. Individuals with any current malignancy, chronic respiratory disease, or acute respiratory illness were excluded from the control group.

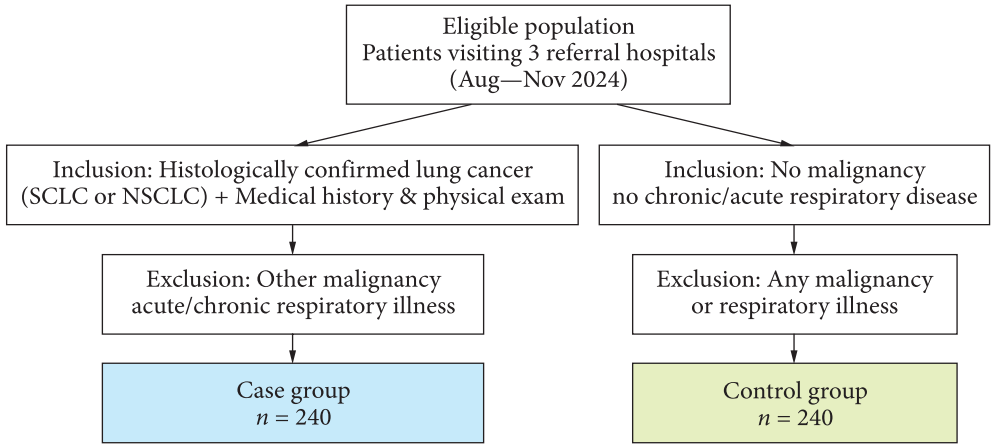
Cases were recruited consecutively from hospitalized patients diagnosed with lung cancer. The minimum sample size required for adequate statistical power was 240 participants per group, calculated based on case–control study assumptions.

Data collection. Clinical and demographic information was collected using medical records and structured data collection forms. The variables included:

- age;
- sex;
- occupation;
- smoking exposure;
- occupational exposure to carcinogens;
- residential environmental conditions;
- indoor household environment;
- history of chronic respiratory diseases (including TB and COPD);
- family history of cancer.

For patients in the case group, additional clinical information was collected, including:

- histological subtype;
- cancer stage;
- metastasis status;
- EGFR mutation status;



Flow diagram of participant selection

• ECOG performance status;
• treatment regimen.

Definition of key exposure variables. Smoking exposure was categorized into four groups:

• never smokers: individuals who had never smoked in their lifetime;
• passive smokers: individuals exposed to tobacco smoke at home or in the workplace;
• former smokers: individuals who previously smoked but stopped smoking for at least 12 months before enrolment;
• current smokers: individuals actively smoking cigarettes or other tobacco products at the time of the study.

Additional smoking variables included age at smoking initiation, number of cigarettes smoked per day, and duration of smoking.

Occupational exposure referred to the long-term exposure to known lung carcinogens in the workplace. Common occupations among participants included construction workers, factory workers, drivers exposed to traffic pollution, miners, and agricultural workers. Relevant exposures included asbestos, silica dust, diesel exhaust, industrial chemicals, and pesticide aerosols.

Residential environment referred to environmental pollution surrounding the household, including proximity to industrial areas, major roads with high traffic density, or other sources of outdoor air pollution.

Indoor household environment was classified as healthy or unhealthy based on the presence of risk factors such as poor ventilation, indoor tobacco smoke exposure, use of biomass fuel for cooking, and household dampness or mold.

Family history of cancer. Family history of cancer was defined as a reported history of cancer among first-degree relatives (parents, siblings, or children). Information regarding cancer history among second-degree relatives was not systematically available in the medical records and therefore was not included in the present analysis.

Statistical analysis. Descriptive statistics were used to summarize baseline participant characteristics. The categorical variables were compared using the Chi-square test, while the continuous variables were analyzed using independent samples *t*-tests. The variables with $p < 0.25$ in the bivariate analysis were included in the multivariate logistic regression model using backward stepwise selection to identify independent risk factors for lung cancer. Because the control group was not completely matched by age, age was included as an adjustment variable in the multivariate model to control for potential confounding. The adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to estimate the strength of the associations between risk factors and lung cancer. Statistical significance was defined as $p < 0.05$.

Ethical approval. The study protocol was approved by the Ethics Committee of the Faculty of Medicine, Universitas Sumatera Utara (No. 1134/KEPK/USU/2024). All procedures were conducted in accordance with ethical standards for medical research involving human subjects. Eligible participants were recruited from three referral hospitals in North Sumatra between August and November 2024. Cases were defined as patients with histologically confirmed lung cancer (SCLC or NSCLC) verified by clinical and histopathological examinations. Controls were individuals without malignancy or chronic respiratory disease recruited from outpatient clinics in the same hospitals. Exclusion criteria for both groups included any

concurrent malignancy or acute or chronic respiratory illness. A total of 240 cases and 240 controls were included in the final analysis (Figure).

Results

Baseline characteristics of participants are presented in Table 1. Sex distribution was similar between groups, with most participants being male. A significant difference in age distribution was observed between groups ($p < 0.001$). The control group contained the higher proportion of participants aged <45 years (20.8%) compared to the cases (6.3%), indicating potential age imbalance between groups. The history of cancer, smoking exposure, occupational exposure, unhealthy indoor environment, and previous respiratory disease were significantly more common among cases than controls, whereas the family history of cancer and general residential environment showed no significant differences.

Comparison of risk factors between groups is summarized in Table 2. Lung cancer patients were more likely to have a history of cancer ($p = 0.012$), occupational exposure ($p = 0.001$), unhealthy indoor environments ($p < 0.001$), and respiratory disease ($p < 0.001$). They also had higher overall risk scores ($p < 0.001$). No significant differences were observed in mean age, family history of cancer, smoking exposure, or residential environment.

Multivariate logistic regression analysis identified several independent risk factors for lung cancer (Table 3). Smoking exposure was strongly associated with lung cancer risk. Individuals with former or current smoking history had more than a three-fold increased risk compared with never smokers (OR 3.42; 95% CI 1.96—5.97). Passive smoking was also associated with increased risk (OR 1.76; 95% CI 1.02—3.04). Occupational exposure remained a significant predictor (OR 1.91; 95% CI 1.13—3.25), and participants living in unhealthy indoor environments had a more than two-fold higher risk of lung cancer (OR 2.53; 95% CI 1.45—4.40). Age was included as an adjustment variable in the model to control for potential confounding.

Discussion

This study identified smoking exposure, occupational hazards, unhealthy indoor environments, and chronic respiratory diseases as important de-

Table 1. **Baseline characteristics of study participants**

Characteristics	Case group ($n = 240$)	Control group ($n = 240$)	p-value
Sex			
Female	59 (24.6%)	58 (24.2%)	
Male	181 (75.4%)	182 (75.8%)	0.915
Age			
<45 years	15 (6.3%)	50 (20.8%)	
45—65 years	162 (67.5%)	112 (46.7%)	
>65 years	63 (26.3%)	78 (32.5%)	<0.001
History of cancer			
None	233 (97.1%)	240 (100%)	
<5 years ago	5 (2.1%)	0 (0%)	
>5 years ago	2 (0.8%)	0 (0%)	0.029
Family history			
None	235 (97.9%)	236 (98.3%)	
Other cancers	3 (1.3%)	4 (1.7%)	
Lung cancer	2 (0.8%)	0 (0%)	0.342
Smoking exposure			
Never	18 (7.5%)	32 (13.3%)	
Passive	51 (21.3%)	31 (12.9%)	
Ex-/current smoker	76 (31.7%)	86 (35.8%)	
Active smoker	95 (39.6%)	91 (37.9%)	0.023
Occupational exposure			
Yes	116 (48.3%)	80 (33.3%)	
No	124 (51.7%)	160 (66.7%)	0.001
Residential environment			
Unhealthy	114 (47.5%)	97 (40.4%)	
Healthy	126 (52.5%)	143 (59.6%)	0.118
Indoor environment			
Unhealthy	74 (30.8%)	41 (17.1%)	
Healthy	166 (69.2%)	199 (82.9%)	<0.001
Respiratory disease			
None	209 (87.1%)	240 (100%)	
COPD	18 (7.5%)	0 (0%)	
Tuberculosis	13 (5.4%)	0 (0%)	<0.001
Risk level			
Mild	12 (5.0%)	34 (14.2%)	
Moderate	92 (38.3%)	103 (42.9%)	
Severe	136 (56.7%)	103 (42.9%)	<0.001

Notes: Chi-square test was used for categorical variables. COPD — chronic obstructive pulmonary disease. Risk level was categorized based on cumulative exposure to smoking, occupational, and environmental pollutants.

terminants of lung cancer risk in North Sumatra. These findings are consistent with the global understanding that lung cancer is largely driven by modifiable environmental and behavioral exposures. Recent global analyses continue to emphasize that tobacco use and environmental exposures remain the dominant contributors to lung cancer incidence worldwide, particularly in low- and middle-income countries where tobacco control and environmental regulations remain limited [13—15].

Table 2. **Comparison of risk factors between lung cancer cases and controls**

Variable	Case group (mean ± SD)	Control group (mean ± SD)	*p*-value
Age	2.20 ± 0.54	2.12 ± 0.72	0.152
History of cancer	1.04 ± 0.23	1.00 ± 0.00	0.012
Family history of cancer	1.04 ± 0.29	1.02 ± 0.13	0.315
Smoking exposure	3.03 ± 0.95	2.98 ± 1.02	0.580
Occupational exposure	1.97 ± 1.00	1.67 ± 0.95	0.001
Residential environment	1.95 ± 1.00	1.81 ± 0.98	0.118
Indoor environment	1.62 ± 0.93	1.34 ± 0.75	< 0.001
Respiratory disease	1.18 ± 0.51	1.00 ± 0.00	< 0.001
Risk level	2.52 ± 0.59	2.29 ± 0.70	< 0.001

Notes: Independent samples *t*-test. Higher mean scores indicate greater exposure or risk severity. Risk level score was derived from combined smoking, occupational, and environmental exposure categories.

Table 3. **Multivariate logistic regression analysis of risk factors for lung cancer**

Variable	*p*-value	Adjusted OR (95% CI)
Age (reference: 45—65 years)		
<45 years	0.081	1.62 (0.94—2.79)
>65 years	0.109	1.34 (0.94—1.92)
Smoking exposure (reference: never smoker)		
Passive smoking	0.041	1.76 (1.02—3.04)
Former/current smoker	<0.001	3.42 (1.96—5.97)
Occupational exposure	0.017	1.91 (1.13—3.25)
Indoor environment (unhealthy)	0.001	2.53 (1.45—4.40)

Notes: Multivariate logistic regression analysis adjusted for age and sex. OR — odds ratio; CI — confidence interval.

The absence of significant sex-related differences between cases and controls in this study is consistent with previous epidemiological studies. Although the majority of lung cancer patients were male, reflecting the higher prevalence of smoking among men in Indonesia, recent international data suggest that the gap between men and women is gradually narrowing due to increasing smoking rates among women and environmental exposure among non-smokers [13, 14]. Recent global cancer statistics have also reported an increasing lung cancer incidence among women in several regions, partly driven by changing smoking patterns and environmental exposures [16].

Age is widely recognized as a major determinant of lung cancer incidence, with risk generally increasing with advancing age due to cumulative exposure to carcinogens and progressive genetic damage. In the present study, differences in age distribution were observed between cases and controls. Because the control group contained the higher proportion of younger individuals, age was treated as a potential confounding variable and included in the multivariate regression model. This approach helps ensure that the estimated associations between environmental exposures and lung cancer risk are not biased by differences in age distribution between groups [17].

Smoking exposure remained the most important behavioral risk factor in this study. The multivariate analysis demonstrated that former or current smokers had a significantly higher risk of lung cancer compared with never smokers. Tobacco smoke contains thousands of carcinogenic compounds, including polycyclic aromatic hydrocarbons (PAHs), nitrosamines, and heavy metals, which induce DNA damage, promote chronic inflammation, and accelerate carcinogenesis [5, 18]. Large cohort studies have shown that smokers have a 15—30-fold higher risk of lung cancer compared to non-smokers, with risk strongly correlated with smoking duration and intensity [18]. Passive smoking was also associated with an increased risk in

this study, supporting evidence that second-hand smoke exposure contributes to lung cancer development, particularly among individuals living with smokers [19]. Recent epidemiological studies further indicate that the combined effects of tobacco smoke and air pollution may amplify lung cancer risk in urban populations, particularly in rapidly developing Asian regions [20].

Occupational exposure also showed a significant association with lung cancer risk. Workers exposed to industrial carcinogens such as asbestos, silica dust, diesel exhaust, and heavy metals have consistently demonstrated higher lung cancer incidence in occupational epidemiology studies. The IARC classifies several occupational agents, including asbestos and cadmium, as Group 1 carcinogens for lung cancer [7]. Similar findings have been reported in large-cohort studies in Asia and Europe, where long-term occupational exposure significantly increased lung cancer mortality [21, 22]. Recent evidence also highlights the role of occupational particulate exposure and industrial pollutants in the increasing lung cancer risk among workers in rapidly industrializing regions [23].

Indoor air pollution was another important determinant identified in this study. Participants living in unhealthy indoor environments had more than twice the risk of developing lung cancer. Indoor air pollution is a major public health concern in many developing countries, where exposure to biomass fuels, poor ventilation, and indoor tobacco smoke is common. Previous studies conducted in India and China have reported similar findings, particularly among non-smoking women exposed to biomass combustion products [24, 25]. Exposure to fine particulate matter (PM2.5) and volatile organic compounds such as benzene, toluene, ethylbenzene, and xylene (BTEX) contributes to oxidative stress, DNA damage, and chronic inflammation, which are important mechanisms in lung carcinogenesis [26, 27]. Recent environmental health research has further demonstrated that long-term exposure to fine particulate matter significantly increases lung cancer incidence and mortality in urban populations [28].

Chronic pulmonary diseases, particularly COPD and TB, were more prevalent among lung cancer cases in this study. Chronic inflammation associated with these conditions may contribute to carcinogenesis through repeated tissue injury, fibrosis, and activation of inflammatory pathways. Epidemiological evidence indicates that a history of TB or COPD is associated with an increased risk of lung cancer in the general population. A recent meta-analysis reported that pulmonary TB confers more than a twofold increase in lung cancer risk [29]. Consistently, a population-based cohort study demonstrated a 1.72-fold higher risk of lung cancer among TB survivors, with a greater risk observed in those with coexisting COPD [30]. Moreover, TB has been shown to significantly increase the risk of developing COPD, further contributing to lung carcinogenesis through persistent airway inflammation and structural lung damage [31].

In contrast, family history of cancer was not significantly associated with lung cancer risk in this study. This finding differs from several large-scale studies conducted in Korea and Western populations, which have consistently reported that a positive family history of lung cancer is associated with an increased risk of disease, with estimated risk elevations ranging from approximately 1.5 to more than 2-fold compared with individuals without such history [12, 32, 33]. The discrepancy observed in the present study may reflect population-specific factors or the stronger influence of environmental exposures, particularly smoking and air pollution, in the North Sumatran population. Nevertheless, prospective cohort evidence indicates that the family history of lung cancer remains an independent risk factor for lung cancer development even after adjustment for major confounders, with significantly increased risk observed in both smokers and never-smokers [33].

Overall, the findings of this study emphasize that lung cancer in North Sumatra is strongly associated with modifiable environmental and behavioral factors. Smoking, occupational exposures, indoor air pollution, and chronic respiratory diseases appear to play major roles in disease development. These findings highlight the importance of strengthening tobacco control policies, improving occupational safety, and reducing indoor air pollution as key strategies to reduce lung cancer burden in high-risk populations. This study provides important regional epidemiological evidence on lung cancer risk factors in North Sumatra, contributing to the development of targeted prevention strategies in high-burden settings.

Strengths and limitations of the study

This study has several important strengths. First, it included a relatively large sample of lung cancer patients and controls recruited from three major referral hospitals in North Sumatra, providing robust epidemiological data from a high-burden region. Second, the study simultaneously evaluated multiple environmental, behavioral, and clinical risk factors, allowing a more comprehensive assessment of determinants associated with lung cancer in this population. Third, the use of multivariate regression analysis enabled adjustment for potential confounding variables, particularly age differences between cases and controls, thereby strengthening the validity of the observed associations.

This study has several limitations that should be considered when interpreting the findings. First, the hospital-based design may introduce selection bias and limit the generalizability of the results to the broader population. In addition, the case and control groups were not strictly age-matched; therefore, age was included as an adjustment variable in the multivariate regression analysis to reduce potential confounding. Information on several exposure variables, including smoking history, occupational exposure, and household environmental conditions, was obtained from medical records and self-reported data, which may introduce recall bias.

Furthermore, exposure intensity and duration for smoking and occupational carcinogens were not quantified in detail, which may have resulted in residual confounding. Environmental conditions were assessed using questionnaire-based information rather than objective measurements of indoor air pollutants. In addition, family history of cancer was limited to first-degree relatives because information on second-degree relatives was not systematically available in the medical records. Despite these limitations, this study provides important epidemiological evidence from a relatively large sample of lung cancer patients and controls in North Sumatra and highlights key modifiable environmental and behavioral risk factors in this high-burden region.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this study.

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ПАЛІННЯ, ФАКТОРИ ДОВКІЛЛЯ ТА ХРОНІЧНІ ЛЕГЕНЕВІ ХВОРОБИ ЯК КЛЮЧОВІ ФАКТОРИ РИЗИКУ РАКУ ЛЕГЕНІ У ПІВНІЧНІЙ СУМАТРІ

Стан питання. Рак легені залишається провідною причиною онкологічної смертності у світі. Захворюваність на рак легені в країнах, що розвиваються, зростає. Визначення специфічних регіональних факторів ризику є важливим для ефективних стратегій профілактики. **Мета** дослідження полягала у визначенні основних детермінант раку легені у Північній Суматрі, Індонезія. **Матеріали та методи.** Проведено спостережне дослідження на базі трьох клінік у Північній Суматрі, Індонезія, від серпня по листопад 2024 року з включенням 240 хворих із гістологічно підтвердженим раком легені та 240 осіб контрольної групи без злоякісних новоутворень або хронічних захворювань дихальних шляхів. Особи, включені до дослідження, мали порівняні характеристики за статтю та місцем проживання, тоді як вікові відмінності між групами були статистично скориговані за допомогою багатофакторної регресійної моделі. **Результати.** Паління було найбільш визначальним фактором ризику порівняно з контрольною групою. Багатофакторний аналіз виявив кілька незалежних предикторів раку легені. Вік до 45 років збільшував ризик більш ніж удвічі (ВШ 2,62; 95% ДІ 1,10—6,21), тоді як у віці понад 65 років відносний ризик був нижчим (ВШ 0,54; 95% ДІ 0,33—0,88). Несприятливі виробничі фактори значно збільшували ризик раку легень (ВШ 1,91; 95% ДІ 1,13—3,25). Підвищений ризик зазначено також щодо несприятливих побутових умов помешкання, зокрема поганої вентиляції та впливу забруднюючих речовин (ВШ 2,53; 95% ДІ 1,45—4,40). Хронічні респіраторні захворювання, зокрема туберкульоз та хронічна обструктивна хвороба легень, були більш поширеними в групі хворих на рак легень в порівнянні з контрольною групою і сприяли підвищенню ризику. **Висновки.** Паління, професійні ризики, нездорове середовище в приміщенні та хронічні захворювання легень є важливими детермінантами раку легені у Північній Суматрі. Стратегії громадського здоров'я, зосереджені на обмеженні тютюнопаління, покращенні безпеки на робочому місці та зменшенні забруднення повітря в помешканнях, можуть суттєво зменшити поширення раку легені у цьому регіоні.

Ключові слова: рак легені, тютюнопаління, професійні шкідливі фактори, забруднення повітря в помешканнях, туберкульоз.