Ann Occup Environ Med. 2024 Jan 31;36:e2
https://doi.org/10.35371/aoem.2024.36.e2
eISSN 2052-4374

Annals of Occupational and Environmental Medicine AOEM

Original Article

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Cooking oil fume exposure and Lung-RADS distribution among school cafeteria workers of South Korea

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Received: Aug 8, 2023
1st Revised: Sep 29, 2023
2nd Revised: Nov 16, 2023
3rd Revised: Dec 12, 2023
Accepted: Jan 3, 2024
Published online: Jan 31, 2024

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ABSTRACT

Background: Cooking oil fumes (COFs) from cooking with hot oil may contribute to the pathogenesis of lung cancer. Since 2021, occupational lung cancer for individual cafeteria workers has been recognized in South Korea. In this study, we aimed to identify the distribution of lung-imaging reporting and data system (Lung-RADS) among cafeteria workers and to determine factors related to Lung-RADS distribution.
Methods: We included 203 female participants who underwent low-dose computed tomography (LDCT) screening at a university hospital and examined the following variables: age, smoking status, second-hand smoke, height, weight, and years of service, mask use, cooking time, heat source, and ventilation. We divided all participants into culinary and non-culinary workers. Binomial logistic regression was conducted to determine the risk factors on LDCT of Category ≥ 3, separately for the overall group and the culinary group.
Results: In this study, Lung-RADS-positive occurred in 17 (8.4%) individuals, all of whom were culinary workers. Binary logistic regression analyses were performed and no variables were found to have a significant impact on Lung-RADS results. In the subgroup analysis, the Lung-RADS-positive, and -negative groups differed only in ventilation. Binary logistic regression showed that the adjusted odds ratio (aOR) of the Lung-RADS-positive group for inappropriate ventilation at the workplace was 14.89 (95% confidence interval [CI]: 3.296–67.231) compared to appropriate ventilation as the reference, and the aOR for electric appliances at home was 4.59 (95% CI: 1.061–19.890) using liquid fuel as the reference.
Conclusions: The rate of Lung-RADS-positive was significantly higher among culinary workers who performed actual cooking tasks than among nonculinary workers. In addition, appropriate ventilation at the workplace made the LDCT results differ. More research is needed to identify factors that might influence LDCT findings among culinary workers, including those in other occupations.

Keywords: Cancer screening; Food services; Cooking oil fumes; Lung-RADS; Female never-smokers

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Abbreviations

ACR: American College of Radiology; ADC: adenocarcinoma; aOR: adjusted odds ratio; BMI: body mass index; CI: confidence interval; CO: carbon monoxide; COF: cooking oil fume; EGFR: epidermal growth factor receptor; GGN: ground glass nodule; LDCT: low-dose computed tomography; Lung-RADS: lung-imaging reporting and data system; NLST: National Lung Screening Trial; PAH: polycyclic aromatic hydrocarbon; PET-CT: positron emission tomography-computed tomography; PM: particulate matter; SCLC: small cell lung carcinoma; UFP: ultra-fine particles; VOC: volatile organic compound; 8hr-TWA: 8-hour total weight average.

Competing interests

The authors declare that they have no competing interests.

Author Contributions

Conceptualization: Yoo C. Data curation: Kim M. Formal analysis: Kim M. Yoo C. Investigation: Kim Y, Lim S, Kwon WJ. Methodology: Kim M, Kim AR, Yoo C. Software: Kim MJ. Validation: Yoo C. Visualization: Kim W. Writing - original draft: Kim M. Writing - review & editing: Yoo C, Kim W, Kim AR.

BACKGROUND

Lung cancer has high morbidity and mortality rates worldwide, with 2.2 million new diagnoses and 1.79 million deaths per year.[1] According to the 2020 Cancer Registration Statistics, 28,949 new cases of lung cancer were diagnosed in Korea, of which 19,657 were men and 9,292 were women.[2] In a national survey of Korea, the incidence of lung cancer among female and non-smokers is gradually increasing, and high-temperature cooking has been identified as potential causes of lung cancer in these groups.[3,4] Lung cancer is a malignant tumor caused by uncontrolled cell growth in the lungs. If not treated early, it can spread to surrounding tissues and organs. Primary lung cancer includes small cell lung carcinoma (SCLC) and non-small cell lung cancer (NSCLC). Of these, NSCLC accounts for 85% of cases and is divided into 3 main pathologic subtypes: squamous cell carcinoma, large cell carcinoma, and adenocarcinoma (ADC).

To date, low-dose computed tomography (LDCT) is the only test recommended for lung cancer screening. In South Korea, LDCT is annually recommended for high-risk individuals aged 55–74 years.[5] Although smoking is a major risk factor for lung cancer,[6] about 25% cases occur in nonsmokers.[7,8]

Recently, the number of smokers has been decreasing due to smoking cessation programs, and cooking oil fumes (COFs) have been cited as a major risk factor for lung cancer besides occupational exposure.[7] In nonsmokers, SCLC is rarely observed, and ADC is the most common. ADC, accompanied by epidermal growth factor receptor (EGFR) mutations, is more common among Asians (50% of NSCLC) than in Westerners (20% of NSCLC).[9] Early diagnosis is necessary as targeted therapies increase survival rates.[10,11]

Cooking with high-temperature frying, stir-frying, and grilling recipes produces COFs, a form of adsorption of polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and formaldehyde onto particulate matter (PM). The International Agency for Research on Cancer has listed frying, emissions from high-temperature as group 2A carcinogen.[12] Due to eating-out culture, COFs have become a major source of indoor air pollution, especially for female workers, and various studies have been conducted.[4,13,14]

Since 2021, occupational lung cancer among cafeteria workers has been recognized in South Korea. This study, we aimed to identify the distribution of lung-imaging reporting and data system (Lung-RADS) in food service workers aged ≥ 55 years or had been working for ≥ 10 years using LDCT and determine factors related to Lung-RADS distribution in cooks and kitchen assistants in charge of actual cooking and nutrition teachers who do not participate in actual cooking.

METHODS

Study participants

Overall, 217 participants undergo LDCT screening at Ulsan University Hospital between June 2022 and August 2022. People aged ≥ 55 and those who had been working for ≥ 10 years were selected. Cooks and kitchen assistants were in the exposed group while nutrition teachers were in the unexposed group. The participants in the exposed group, culinary workers, were responsible for cooking, serving, transporting, and maintaining food service equipment and utensils. Those in the nonexposed group, nonculinary workers, were responsible for supervising cooks and performing administrative and supervisory tasks including meal planning and distribution. All 217 participants were female, and individuals with tuberculosis, asthma, or cancer other than lung cancer before screening (n = 14) were excluded from the study. Patients diagnosed with lung cancer 3 months before screening and underwent LDCT were regarded as 4X. Finally, 203 participants (167 exposed and 36 unexposed) were selected for data analyses.

General characteristics

Data were collected using a self-reported questionnaire before LDCT screening for individuals who agreed to participate in the study (**Supplementary Data 1**). The questionnaire included questions on the participant's age, smoking status, passive smoking, height, weight, service years, use of masks when cooking, cooking time at home, heat source at home, and home ventilation for both exposed and unexposed individuals. The exposed group was further questioned about the proportion of cooking duties at work, number of recipes they cooked, amount of heat exposure per week, main ingredients, and ventilation conditions at the workplace.

We categorized the extent to which cooking dominates the workday into 4 levels: i) most of the time, ii) more than half, iii) less than half, and iv) others, with the highest level being defined as high proportion of cooking tasks. For cooking (grilling, boiling, stir-frying, frying, and others), we classified respondents doing all the frying, stir-frying, and grilling as being exposed to recipes that use a lot of fat or oil. For recipes using heat, a response was classified as follows: i) at every meal, ii) more than half, iii) less than half, and iv) others, and a response of daily was considered high exposure. For frequently used ingredients (vegetables, meat, fish, others), high-exposure group were those who responded that they mainly use both meat and fish. Workplace ventilation was classified as follows: i) open window only, ii) open windows and turn on fans, iii) fans only, and iv) no special ventilation, respondents were considered to have better ventilation if they reported using both windows and fans.

Cooking time at home was classified as high exposure when exceeded 2 hours, and for the heat source at home, electric fuel was considered low exposure. For ventilation at home, we defined better ventilation as the use of both windows and fans, same as at the workplace.

LDCT results and Lung-RADS

The American College of Radiology's (ACR) Lung Cancer Screening Registry uses the Lung-RADS categories and updated Lung-RADS ver1.1 (**Supplementary Table 1**) produced by the ACR in 2019.[15] Lung-RADS, which is administered to lung cancer high-risk group aged 55–74 years with a smoking history of ≥ 30 pack-years, was adapted, and used for screening subjects who were all nonsmokers. Of these, Category ≥ 3 requiring follow-up within 6 months was defined as Lung-RADS-positive.

Lung-RADS version 1.1

- Category 1: Negative and definitely benign nodules.
- Category 2: Benign appearance and a likelihood to be malignant < 1%.
- Category 2b: Nodules that may correspond to categories 3 or 4 but are highly suspected to be benign considering the high tuberculosis prevalence in Korea.
- Category 3: Probably benign but with a likelihood of ≥ 1% to be malignant, requiring 6 months of LDCT follow-up.

Category 4A: Suspicious nodules suspected to be lung cancer with a likelihood of 5%–15% to be malignant, requiring 3 months of LDCT follow-up or positron emission tomography-computed tomography (PET-CT) or bronchoscopy.

Category 4B, 4X: very suspicious nodules suspected to be lung cancer with a likelihood of > 15% to be malignant, requiring Chest CT, PET-CT, or tissue sampling.

LDCT was performed using SIMENS SOMATOM go.TOP (Siemens Medical Solutions, Forchheim, Germany), and the protocol was as follows: tube voltage: 110 kVP; tube current: 14 mAs; rotation: 0.33 seconds; collimation: 0.6 mm; pitch: 1.5 for 16-channel scanners or higher. Images were read by a specially trained radiologist.

Workplace environmental monitoring

The work environment measurements were monitored by the Environmental Health Team of the Occupational Health Center of the city where the schools are located. Acetaldehyde, formaldehyde, acrylamide, benzene, ozone, respirable PM, carbon monoxide (CO), noise, and high temperature were measured in 6 schools from July 13 to July 26 in 2022, using personal and regional samples.

Statistical analysis

Continuous variables were presented as mean values and standard deviations; categorical variables were presented as frequencies and percentages. All participants were divided into culinary and nonculinary workers, and characteristics of each group were compared using the χ^2 test or Fisher's exact test and the independent-sample t-test. We defined culinary workers as a subgroup of participants who are expected to have high exposure to COFs. Subgroup analyses were performed using the same method. LDCT findings were categorized using Lung-RADS version 1.1, and Category ≥ 3 requiring follow-up within 6 months was defined as Lung-RADS-positive, and groups were compared using the χ^2 test. To adjust for confounding variables and analyze the effect of each variable on Lung-RADS, we performed binomial logistic regression analyses for the overall group and culinary group. All p-values < 0.05 were considered statistically significant. All statistical analyses were performed using SPSS Statistics version 24 (IBM Corp., Armonk, NY, USA).

Ethics statement

The present study protocol was reviewed and approved by the Institutional Review Board (IRB) of Ulsan Hospital (IRB No. UMC 2023-03-013).

RESULTS

General characteristics of study participants

Of 203 participants, 167 and 36 were in the exposed and unexposed groups, respectively. The mean age was 55.87 ± 3.58 and 48.19 ± 6.39 years in the exposed and unexposed groups, respectively, and it was significantly higher for the culinary workers (**Table 1**, $p = 0.000$). The participants were all female nonsmokers, and no statistically significant differences were observed between the 2 groups for passive smoking. Those in both groups worked for a mean period of 18.37 ± 4.91 and 20.97 ± 8.33 years, respectively, in food service, although no statistically significant exists ($p = 0.079$). The participants in the exposed group were more likely to wear masks before the pandemic than those in the unexposed group ($p = 0.004$). The proportion of participants who cooked at home for ≥ 2 hours was also higher in the exposed

Table 1. Baseline characteristics of participants according to work

Characteristics	Exposed (n = 167)	Unexposed (n = 36)	*p*-value
Sex			
Female	167 (100.0)	36 (100.0)	
Smoke			
Never-smoker	167 (100.0)	36 (100.0)	
Passive smoking			0.215
Non-exposure	153 (91.6)	35 (97.2)	
Exposure	14 (8.4)	1 (2.8)	
Age (years)	55.87 ± 3.58	48.19 ± 6.39	0.000***
BMI (kg/m^2)	23.57 ± 2.28	22.51 ± 2.77	0.015*
Employment period (years)	18.37 ± 4.91	20.97 ± 8.33	0.079
Mask-wearing			0.004**
No	47 (28.1)	19 (52.8)	
Yes	120 (71.9)	17 (47.2)	
Cooking hour at home			0.000***
Less than 2 hours	92 (55.1)	34 (94.4)	
More than 2 hours	75 (44.9)	2 (5.6)	
Heat source at home			0.006**
Gas combustion	154 (92.2)	27 (75.0)	
Electric plates and appliance	13 (7.8)	9 (25.0)	
Ventilation at home			0.012*
Only a fan or a window	12 (7.2)	8 (22.2)	
Both a fan and a window	155 (92.8)	28 (77.8)	

Values are presented as number (%) or mean ± standard deviation. The *p*-values were calculated using the χ^2 test and the independent t-test. The *p*-values were analyzed by Fisher's exact test (passive smoking, heat source in the house, ventilation in the house).
BMI: body mass index.
*p < 0.05; **p < 0.01; ***p < 0.001.

group (75; 44.9%) than in the unexposed group (2; 5.6%) (p = 0.000). For heat sources used at home, the culinary workers relied significantly more on liquefied gas, with 154 (92.2%) participants in the exposed group and 27 (75.0%) participants in the unexposed group (p = 0.005). For home ventilation, both groups used at least one method of ventilation, and the exposed group was found to be more thoroughly ventilated with 155 (92.8%) participants adopting both methods compared to 28 (77.8%) participants in the unexposed group.

LDCT results of study participants

Chi-square analyses of Lung-RADS distribution in the exposed and unexposed groups revealed 17 participants to be Lung-RADS-positive, with all of them being in the exposed group, culinary workers. This was statistically significant (**Table 2**, p = 0.031). In the exposed group, 111 (65.5%) participants had Lung-RADS Category 1, 36 (21.6%) had Category 2, 3 (1.8%) had Category 2b, 8 (4.8%) had Category 3, 4 (2.4%) had Category 4A, 1 (0.6%) had Category 4B, and 4 (2.4%) had Category 4X. In the nonexposed group, there were 27 (75.0%) participants with Lung-RADS Category 1, 8 (22.2%) with Category 2, and 1 (2.8%) with Category 2b, with no participant having Category ≥ 3. Binomial logistic regression analyses of body mass index (BMI), passive smoking, age, years of work experience, mask use, time spent

Table 2. Lung-RADS distribution of participants according to work classification

Lung-RADS	Total (n = 203)		*p*-value
	Exposed (n = 167)	Unexposed (n = 36)	
Negative	150 (89.8)	36 (100.0)	0.031*
Positive	17 (10.2)	0 (0.0)	

Values are presented as number (%). The *p*-values were calculated using χ^2 test. The *p*-values were analyzed using Fisher's exact test (Lung-RADS distribution).
Lung-RADS: lung-imaging reporting and data system.
*p < 0.05.

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cooking at home, heat source at home, ventilation status, and occupation did not identify any variables that significantly affected Lung-RADS results.

Subgroup analyses of cafeteria cooking workers

Subgroup analyses were performed on the exposure group where many Lung-RADS-positive participants were observed. In subgroup analysis, 17 (10.2%) Lung-RADS-positive and 150 (89.8%) Lung-RADS-negative individuals were analyzed out of a total of 167 exposed individuals. Only workplace ventilation differed between the Lung-RADS-positive group (12, 70.6%) and Lung-RADS-negative group (141, 94.0%), and this difference was statistically significant (**Table 3**, $p = 0.007$). Binomial logistic regression analyses performed after adjusting for age, passive smoking, BMI, years of work, mask-wearing, cooking time at home, cooking time at work, favorite recipes, heat exposure during cooking, and favorite ingredients showed that the odds ratio (OR) for Lung-RADS-positive days was 14.89, and the *p*-value was significant when thorough ventilation was used as the reference (**Table 4**, $p = 0.000$). For household heat sources, the OR was 4.59 and *p*-value was significant when liquid fuel use was used as the reference ($p = 0.041$).

Table 3. Baseline of characteristics of subgroup (culinary workers)

Characteristics	Lung-RADS- positive (n = 17)	Lung-RADS-negative (n = 150)	*p*-value
Passive smoking			0.570
Non-exposure	16 (94.1)	137 (91.3)	
Exposure	1 (5.9)	13 (8.7)	
Age (years)	56.47 ± 3.36	55.81 ± 3.61	0.475
BMI (kg/m^2)	24.22 ± 1.94	23.50 ± 2.31	0.215
Employment period	18.78 ± 5.96	18.33 ± 4.79	0.719
Mask wearing			0.551
No	5 (29.4)	42 (28.0)	
Yes	12 (70.6)	108 (72.0)	
Recipe			0.538
Oil-intensive recipes	9 (52.9)	91 (60.7)	
Oil-free recipes	8 (47.1)	59 (39.3)	
Ingredient			0.892
Fatty food (both fish and meat)	9 (52.9)	82 (54.7)	
Low fatty food	8 (47.1)	68 (45.3)	
Cooking hours at home			0.400
Less than 2 hours	11 (64.7)	81 (54.0)	
More than 2 hours	6 (35.3)	69 (46.0)	
Heat source at home			0.132
Gas combustion	14 (82.4)	140 (93.3)	
Electric plates or appliance	3 (17.6)	10 (6.7)	
Ventilation at home			0.649
Only a fan or a window	1 (5.9)	11 (7.3)	
Both a fan and a window	16 (94.1)	139 (92.7)	
Cooking at the workplace			0.411
Only cooking	7 (41.2)	47 (31.3)	
With other work	10 (58.8)	103 (68.7)	
Recipe with heat			0.612
Every day	9 (52.9)	89 (59.3)	
Not every day	8 (47.1)	61 (40.7)	
Ventilation at the workplace			0.007**
Only a fan or a window	5 (29.4)	9 (6.0)	
Both a fan and a window	12 (70.6)	141 (94.0)	

The *p*-values were calculated using the χ^2 test and the independent t-test. The *p*-values were analyzed using Fisher's exact test (passive smoking, heat sources at the home, ventilation at the home, ventilation at the workplace).
Lung-RADS: lung-imaging reporting and data system; BMI: body mass index.
**$p < 0.01$.

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Table 4. The adjusted odds ratios and 95% confidence intervals for the associations between different variables with lung-imaging reporting and data system-positive in subgroup analyses

Variables (Classification)	Crude model	Model 1
Heat source at home		
Gas combustion	1.00 (reference)	1.00 (reference)
Electric plates and appliance	3.00 (0.738–12.194)	**4.59* (1.061–19.890)**
Ventilation at home		
Both a fan and a window	1.00 (reference)	1.00 (reference)
Only a fan or a window	0.79 (0.096–6.524)	0.17 (0.015–1.863)
Ventilation at the workplace		
Both a fan and a window	1.00 (reference)	1.00 (reference)
Only a fan or a window	**6.53** (1.885–22.602)**	**14.89*** (3.296–67.231)**

Bold fonts refer to statistically significant results. The adjusted odds ratio was calculated via binomial logistic regression analyses (Model 1: adjusted for passive smoking, age, BMI, employment period, wearing a mask before COVID-19, recipe, ingredient, cooking hours at the home, cooking at the workplace, recipe with heat). There is no statistical significance in binomial logistic regression analyses of the entire study population (passive smoking, age, BMI, employment period, wearing a mask before COVID-19, cooking hours at the home, heat source at the home, ventilation at the home, work classification).
BMI: body mass index; COVID-19: coronavirus disease 2019.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Workplace environmental monitoring

Six schools in the city (4 elementary schools, one middle school, and one high school) were surveyed from July 13 to July 26 in 2022. Measurements were conducted for acetaldehyde, formaldehyde, acrylamide, benzene, ozone, respirable PM, CO, noise, and high temperature (**Table 5**). Underground (C), newly established school on the ground floor (D), semi-basement but fully equipped with electricity (E), ozone was measured higher than the exposure standard of 0.08 ppm.; 8-hour total weight average (8hr-TWA) 0.0954 ppm (C, personal sample), 0.0911 ppm (C, regional sample) 0.0872 ppm (D, personal sample), and 0.1106 ppm (E, regional sample), respectively. The temperature was measured above the exposure standard of 30.0°C in a newly established school on the ground floor (D); 31.9°C (D, regional sample). No values exceeding exposure limits were found for acetaldehyde, formaldehyde, acrylamide, benzene, respirable PM, CO, and noise. For CO, 28 ppm and 20 ppm were measured in local samples for 3 hours in (D) but 10.5 ppm and 7.5 ppm were measured in the 8hr-TWA, which were below the standard, and in the school (F) where fried meals were cooked on the day of measurement, the CO concentration was confirmed to be 48 ppm and 5 ppm for 3 hours of exposure but 18 ppm and 5 ppm were measured in the 8hr-TWA, which were below the standard.

DISCUSSION

The study aimed to determine the LDCT results among school cafeteria workers and explore risk factors for its. The number of culinary workers who was identified as Lung-RADS-positive was 17 (10.2%), furthermore Category 4A, 4B and 4X were 4 (2.4%), 1 (0.6%) and 4 (2.4%). In a subgroup analysis of culinary workers, the use of electric plates and appliances as a heat source at home and poor ventilation at workplace increased the likelihood of Lung-RADS-positive. EGFR mutations are found in 50% of nonsquamous cell carcinomas in Asian populations and EGFR-targeted therapies are more effective in women, ADC, nonsmokers, and East Asians, thereby necessitating early detection.[9-11] In a large descriptive study conducted at a single institution in South Korea, the incidence rates of interval cancer (94.6%), surgery (96.4%), and early-stage lung cancer (Stage 1 and Stage 2, 92.7%) among nonsmokers were significantly higher than those among smokers.[16] To date, LDCT is the

Table 5. Workplace environmental monitoring results by school

Place	Acetaldehyde	Formaldehyde	Acrylamide	Benzene	Ozone	PM	Heat	CO	Noise
(A)	-	0.0063	-	-	0.0471	0.0755	27.9	-	73.0
(B)	-	0.005	-	-	0.0768	0.1971	23.8	-	79.7
(C)	-	0.0234	-	-	0.0954	0.1999	23.4	-	74.9
(D)	-	0.0015	-	0.01475	0.0872	0.1614	31.9	10.5	70.5
(E)	0.0094	0.0016	-	0.1521	0.1106	0.1707	21.9	-	74.2
(F)	0.0135	0.0028	-	-	-	0.0631	26.9	18	67.0

Semi-basement (A), Newly established cafeteria in the semi-basement (B), Underground (C), Newly established school on the ground floor (D), Semi-basement, but fully equipped with electricity (E), Mainly prepared a fried food menu on the day of measurement (F).
PM: particulate matter; CO: carbon monoxide.

only screening test recommended for lung cancer screening. The National Lung Screening Trial (NLST), a large-scale randomized controlled trial conducted in the United States, provides evidence to support LDCT use for screening. The NLST trial compared lung cancer screening in Americans with a smoking history of at least 30 pack-years and no more than 15 years of smoking cessation in an LDCT screening group (26,713) and chest X-ray control group (26,722), and demonstrated a significant reduction in lung cancer mortality and overall mortality in the LDCT group.[17] The Dutch-Belgian Randomized Lung Cancer Screening Trial, published in 2018, also demonstrated a reduction in lung cancer mortality.[18]

In 1997, the National Institute of Occupational Safety and Health estimated that occupational cancer accounted for 4% of all cancer-related deaths, and lung cancer accounted for 10% of all occupational cancer-related deaths.[19] Occupations with a higher risk of lung cancer include welding, painting, foundry work, and mining.[20] In about 25% of cases, lung cancer occurs in nonsmokers, and its causes include chronic inflammation, infections, family history, environmental exposure, and occupational exposures to substances such as asbestos, arsenic, and chromium.[7,8,21]

Cooking with high-temperature frying, stir-frying, and grilling recipes can produce COFs, which are adsorbed PAHs, VOCs, and formaldehyde on PM and ultra-fine particles (UFP).[12] Previous reports have indicate that the chemical compositions of COFs can vary depending on the type of oil used, type of ingredient, and cooking method.[14] Although the toxic mechanisms of COF remain unknown, a recent study demonstrated that oxidative stress and endoplasmic reticulum stress interact to cause lung injury in female rats.[22]

A study of the relationship between cooking fumes and lung cancer in Chinese women found a dose-response relationship with cooking time-years,[13] and a study conducted on Norwegian cooks found that the incidence of respiratory symptoms was proportional to the extent to which frying was performed.[23] When comparing the eating habits, it was found that the proportion of stir-fried dishes was low in Korea compared to China and Taiwan but the proportion of grilled or fried dishes was relatively high. The situation of food service workers in Korea is not considered to differ significantly from that of populations identified as being at high risk in epidemiologic studies conducted in Taiwan and China.[24]

In women, COFs are a risk factor for lung cancer, regardless of the individual's smoking status, and the risk varies with the extent of ventilation.[25] In this study, we also found a significant reduction in LDCT positive with both mechanical and window ventilation in a subgroup analysis of culinary workers. When validating ventilation facilities of school cafeteria in Ulsan, 30 schools showed 13 cases of inadequate hardware management of rooftop blowers (broken facilities, insufficient capacity, and non-injected lubricant oil) and 5 cases of poor software maintenance of facilities (poor cleaning and non-operation of ventilation facilities). Meta-analyses conducted in China have reported an increased risk of lung cancer when fume extractors are not used or ventilation is inadequate,[4,25] and a study in Taiwan found that the long-term use of fume extractors reduced the risk of lung cancer by ≥ 50% in female nonsmokers, with the effect being greater with a higher frequency of cooking.[13]

Previous studies have shown that gas combustion in commercial settings has high concentrations of PM2.5, PM10, or VOC, NO, and CO than electricity.[26-28] Nevertheless, in our study, there were significantly more LDCT-positive participants when electric induction was used at home; however, this may be due to the ventilation system, ingredients used during cooking, or recall bias. In other studies, UFP concentration is higher in gas combustion than in electricity in most cases when cooking for 5 minutes; however, it was found that electricity also produces a large amount of UFP, especially when cooking fatty foods, and the UFP is higher than that in gas combustion.[29] This shows that fatty foods and oils are associated with the occurrence of UFP, and the UFP size is also affected by them. Per our findings, the difference in the total concentrations of PM10 and VOCs between heating sources varied depending on whether the cooking was done at home or in a restaurant, and that the concentration of PM10 was not affected by the heating source when home and restaurant cooking were combined.[26]

COFs generated during cooking are mixtures of a variety of compounds, including PAHs, formaldehyde, acetaldehyde, acrylamide, and acrolein. In this study, the working environment in the cafeteria of 6 schools was tested, and it was found that ozone and high-temperature work exceeded the standard. However, these 2 factors are not associated with lung cancer development, and values below the threshold were found for acetaldehyde, formaldehyde, acrylamide, benzene, respirable PM, CO, and noise; therefore, it was impossible to determine which of the compounds COFs influenced the lung cancer screening results. Workplace measurements in the cafeterias of 24 South Korean schools showed that while usual concentrations did not constitute a problem, cooking with oil-intensive recipes temporarily increased concentrations of formaldehyde, PAHs, acrolein, PM2.5, and CO.[30] Previous reports have identified short-term, high-dose exposures, which is likely because the compositions and concentrations of COFs can vary depending on the type of oil used, cooking method, cooking temperature, and type of food.[14] Despite the high cost and difficulty of conducting workplace studies, large-scale workplace measurements of cooking workers are required to access short-term exposures and the types and concentrations of COF components based on the type of work, ingredients used, cooking method, and time required.

This study has certain limitations. First, it is a cross-sectional study, which makes it difficult to establish causality; thus, well-controlled research such as cohort study is required. Second, the results are based on self-reported questionnaire, this may be subjected to recall biases. Third, monitoring in the same region did not identify any substances that contribute to lung cancer. Fourth, it does not take into account environmental exposures such as radon, asbestos, and exposure from nearby industrial facilities. Fifth, it was impossible to determine what level of protective mask was worn by study participants. Additionally, we categorized nutrition teachers as nonculinary workers who are more likely to be exposed to COFs than general office workers, whereas they should have been studied as a more appropriate comparison group. And due to limited sample size of the study, the CIs in the multivariate analysis were wide and the results may not be generalized.

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Further research is required to investigate the number of meals or frequency of foods that can generate large amount of COFs. These factors are also taken into account when evaluating work-related lung cancer in Korea. Studies have reported associations between foods, oil, cooking methods, and number of meals with lung cancer.[31,32] Irritants in COFs can induce respiratory symptoms such as nasal congestion, chronic cough, and breathing difficulty.[33] According to a study, having ocular irritation symptoms is associated with an increased risk of lung cancer.[32] So complaining symptoms, such as ocular or respiratory symptoms, should be further analyzed.

To the best of our knowledge, this is the first study to analyze LDCT findings in Korean culinary workers. When compared to nonculinary workers, we found a significantly higher number of Lung-RADS-positive individuals in the culinary group, with 4X being observed in 4 of them, and 2 of them were ADC. Retrospective cohort study of 4,365 nonsmoking women aged 40–74 years in South Korea, the initial LDCT positive rate was 6.8%, and in a study conducted in Taiwan, it was 3.6% (64 out of 1,763 asymptomatic men and women aged ≥ 40 years), which is lower than 8.4% in the entire study population and 10.2% among the culinary workers of this study.[34,35] When comparing initial Lung-RADS results in this study with those of Korean cohort studies conducted on nonsmokers, despite differences in age and disease history, culinary workers in this study had a higher rate of Lung-RADS-positive than the rates found in both studies (**Supplementary Table 2**).[16,34] The exposed group worked for a mean duration of 18.37 ± 4.91 years, whereas the unexposed group worked for longer. Other studies have suggested that the risk of lung cancer increases with the duration of cooking[36]; however, in this study, no lung cancer cases were diagnosed at the 6-month follow-up appointment, except for a 57-year-old woman with 17 years of cooking experience diagnosed with right upper lung ADC and underwent video-assisted thoracic surgery lobectomy 6 months before LDCT and a 57-year-old woman with 16 years of cooking experience who fell into Category 4X at screening and was later confirmed to have ADC via histology. Nonsmokers with lung cancer are more likely to have previously detected nodules that progress to cancer than to experience new interval cancer that was not initially detected.[16] It is necessary to check not only LDCT-positive results but also the actual lung cancer incidence through follow-up examinations and conduct screening examinations for cooking workers who are not included in the screening population due to retirement or leaves of absence, and also to confirm the association between LDCT results and lung cancer incidence and duration of cooking work to confirm the dose-response relationship and confirm the association with lung cancer.

Besides COFs, culinary workers are exposed to heat, noise, musculoskeletal demands, and are at risk not only in the cafeteria but also in other areas of the workplace.[37-39] Most of the research conducted on cooking and COFs so far has been conducted in China and Taiwan, and it is known that improper cooking conditions and combustion appliances are the problem.[4,13,25] Studies of culinary workers in other large-scale cooking facilities such as hospitals and military bases, as well as smaller catering establishments with outdated equipment, should be conducted to identify appropriate lung cancer risk groups and maximize the cost-effectiveness of screening.

CONCLUSIONS

Although the workplace measures in this study did not identify factors that could influence Lung-RADS findings, there was a significantly higher rate of Lung-RADS-positive among culinary workers who performed actual cooking tasks compared to nonculinary workers. We analyzed lung cancer screening test results by occupation and found that occupational exposure to COFs can affect the development of lung cancer and that ventilation affects lung cancer screening results. If further analyses confirm the dose-response relationship between cooking fume exposure and Lung-RADS findings, including not only cafeteria workers but also other cooking workers, it will provide a basis for future work environment improvement measures for cooking workers and health promotion policies through specialized health examinations.

ACKNOWLEDGMENTS

The authors thank Ms. Nang Jung Kim, from Occupational and Environmental Health Center in Ulsan University Hospital, for her informational assistance for this study.

SUPPLEMENTARY MATERIALS

Supplementary Data 1

School cafeteria worker health screening questionnaire

Supplementary Table 1

Lung-RADS version 1.1

Supplementary Table 2

Comparing initial Lung-RADS results with those of a cohort study conducted on non-smokers in Korea

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