Association of Wildfire Smoke Exposure and Medical Utilization in Korea

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Association of Wildfire Smoke Exposure and Medical Utilization in Korea

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Kihyun Lee

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박사학위논문을 작성 제출하며, 제가 지금의 제 딸아이만큼 어렸을 때, 커서 박사가 되겠다는 이야기에 부모님께서 이박사라며 좋아하셨던 기억이 떠오릅니다. 포부보다는 재롱에 가까웠지만 그런 추억이 저를 지난한 학위과정으로 이끌었다고 생각합니다.

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이기현

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Association of Wildfire Smoke Exposure and Medical Utilization in Korea

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Background

The characteristic topography and climate often affect the occurrence of large-scale wildfires in the Eastern Gangwon-do region of Korea. However, there are no studies on the health effects of these wildfires in Korea. This study aimed to analyze the differences in medical utilization between a wildfire-affected area and an adjacent non-affected area before and after a wildfire in 2019 in Gangwon-do, Korea.

Materials and Methods

The data which was used in this study was extracted from the medical usage data of the Korean National Health Insurance Corporation. Rates of medical utilization were determined for citizens of a wildfire-affected area in the Eastern Yeongdong region and a non-affected area in the Western Yeongseo region. Logistic regression analysis was performed considering an increase in medical use per individual as a dependent variable; age, sex, income, smoking, drinking, and exercise were included as confounding variables.

Results

The odds ratio for medical utilization in Yeongdong region increased significantly after 3 days, 3 months, and 1 year after a fire occurred, compared with Yeongseo region. The ORs (95% CI) are 1.026 (1.001 - 1.051), 1.098 (1.084 - 1.111), and 1.029 (1.018 - 1.040), respectively.

Conclusions

The results of this study confirmed that the use of medical care increased for residents of a wildfire-affected area, compared with those of an adjacent non-affected area. This is the first study on the relationship between wildfires and inpatient medical utilization in Korea.

Key words: wildfire, health impact, medical utilization, admission

I. INTRODUCTION

Approximately 400 wildfires occur annually in Korea [1]. Most wildfires occur in early April during the dry season. According to Korea's wildfire statistics for the past 50 years, Gangwon-do seems to be the most vulnerable region in terms of the area damaged by wildfire [2]. Large-scale wildfires occur frequently in the Eastern part of Gangwon-do (Yeongdong region), where there are many simple coniferous forests, mainly pine trees that are 20–30 years old, which are vulnerable to wildfires, as well as high temperature and dryness from the peon phenomenon [3, 4]. On April 4, 2019, a massive wildfire occurred in Goseong and Sokcho, Gangwon-do. People in Goseong and Sokcho, who were exposed to wildfire smoke, were concerned about its potential health effects. At that time, there was a discernible difference between the wildfire-affected area in Eastern Gangwon-do and the Western part of Gangwon-do because of the atmospheric integrated environmental index and fine dust concentration due to the wildfire and a westerly wind [5].

Wildfires do not result from the combustion of a single component, but from the burning of various vegetation, building, and other materials, which emit many air pollutants. The composition of wildfire smoke is complex and dynamic, and hence difficult to characterize and model. However, it is generally known that carbon monoxide, nitrogen dioxide, ozone, particulate matter, polycyclic aromatic hydrocarbons, volatile organic compounds such as benzene, and various heavy metals are emitted from wildfire smoke [6].

These contaminants reduce the oxygen-carrying capacity of the blood, resulting in tissue hypoxia, irritation of the nasal passages and respiratory tract, and a variety of pulmonary responses being induced, including reduced lung function, such as bronchoconstriction. Contaminants also elicit adverse hematological, neurological, and immunological effects. A study of German women found that women living within 50 meters of a major road had a small but significantly increased cardiorespiratory death rate, with nitrogen dioxide (NO_2) and PM_{10} similar to wildfire smoke [7]. Wildfires are also known to increase the demand for health services and paradoxically reduce access to medical facilities. In addition, an increase in indoor pollution caused by wildfire combustion materials has been reported, along with health effects due to environmental pollution around the occurrence of wildfires [8, 9].

The health effects of gases and aerosols from wildfires are difficult to quantify. However, existing studies have shown that wildfire smoke contributes to eye, mucous membrane, and respiratory irritation, reduced lung function, bronchitis exacerbation, asthma, and heart failure, increasing hospital visits in smoke-exposed people. Dohrenwend et al. reported that the average number of visits to the emergency room significantly increased during the period when there was a fire by comparing the number of emergency room visits before and after a wildfire in California, America, a common area for wildfires [10]. In Australia, where wildfires are also frequent due to the hot and dry climate and an abundance of eucalyptus trees, Hanigan et al. reported that the number of hospitalizations for respiratory diseases increased by 4.8% with an increase of 10 $\mu g/m^3$ of particulate

matter (PM_{10}) [11]. Respiratory morbidity has the strongest evidence to be associated with wildfire smoke, and there is a statistically significant adverse association. In a cross-sectional study, primary care increased compared to the same period in the previous year when there was no fire. But, it is unclear whether hospitalizations increased due to high acute exposure in the short term and/or whether hospitalizations increased due to low-level exposure accumulated over a long period of time [12, 13]. Adverse effects of cough, wheezing and eye irritation have been observed [14]. PM_{10} is the most common contaminant in cardiovascular disease research. Most PM_{10}-CVD studies did not find a significant association, but a US study found that a 100 μg/m^3 increase in $PM_{2.5}$ associated with wildfire smoke significantly increased the number of emergency room visits for congestive heart failure (CHF) by 42% (95% CI: 5% - 93%) [15]. Other air pollutants from wildfires are under-researched and their effects on cardiovascular disease are uncertain.

While previous studies on the health effects of wildfires have focused on acute effects that occur within days or weeks of exposure, Landguth et al. found that average $PM_{2.5}$ concentrations during wildfire season were positively correlated with flu outbreaks that occurred 1–10 months later [16]. Henderson et al. estimated that air pollution from wildfires will induce systemic inflammation and cause long-term heart disease [17]. Johnston et al. estimated the global mortality from daily and annual exposure to wildfire smoke and $PM_{2.5}$ between 1997 and 2006. Research data shows that the estimated average annual mortality associated with wildfire smoke exposure is 339,000 worldwide. The authors estimate of 339,000 annual deaths is composed of 81% mortality due to chronic exposure

and 19% due to sporadic exposure [18]. However, further research is needed to determine whether exposure to wildfires has adverse long-term effects.

Between August and November 1997, air pollution from wildfires that engulfed Indonesia led to a 1.2 percentage point decrease in survival for the affected child and infant [19]. In a study by Ignoti et al. using an environmental exposure index expressed as a percentage of time per year of high $PM_{2.5}$ concentrations in Brazil, Risk of respiratory hospitalizations associated with wildfire smoke was higher in children (under 5 years of age) compared to other age groups [20]. Although there are insufficient studies to show that people with low socioeconomic status are vulnerable to the negative health effects of wildfire smoke, considering the similarity to air pollution, wildfire smoke may also increase the likelihood of adverse health effects in the socially disadvantaged [21]. In fact, older people and people with pre-existing cardiopulmonary disease may experience more severe short-term and chronic symptoms [22].

In the future, the impacts of climate change will increase a substantial health burden as wildfires become more frequent, more intense and more likely to occur over the long term. The health effects of wildfire smoke are an obvious threat. In Korea, there are few studies on the health effects of wildfires. Kim et al. analyzed relationship with the birth weight of infant and wildfire smoke exposure that occurred simultaneously in five small towns adjacent to the east coast of Gangwon-do in April 2000 and observed a weight loss of about 1% due to the wildfire. It has been suggested that wildfire smoke exposure may cause fetal growth retardation and developmental delay [23].

Due to the large-scale wildfires that occur every year, interest in wildfire response systems is growing. Although most of the previous studies have been conducted in other countries, it is necessary to study the health effects of wildfires in Korea because wildfires have combustion characteristics that differ depending on the topography, forest characteristics, and climate. After identifying the health effects of wildfires, we set out to confirm increased medical use caused upon the occurrence of wildfires and to examine the patterns of medical use to provide a basis for improving health monitoring and wildfire response systems after wildfires. Therefore, it has meaning as basic data for establishing an effective risk communication networks and public health responses.

II. MATERIALS AND METHODS

A. Data description

The National Health Insurance Service (NHIS), operated by the Korean government, manages data on medical services provided to patients by all medical institutions in Korea [24, 25]. The NHIS database contains information about medical institutions and patients, such as visit date and time, the total number of patients, claimed diagnosis, prescriptions, hospitalization and discharges, and medical services [26]. For comparison before and after wildfires among the customized data provided by the NHIS, from April 2017 to December 2019, the data on qualifications and insurance premiums, death, statement details, medical treatment details, diagnosis history, nursing institutions, and general health checkup questionnaire and the health checkup results were merged 2 years before the outbreak of a wildfire. Data from 2019 were used to assess health impacts after wildfires and were compared with data from 2018. For 2017 data, we confirmed the presence of underlying diseases among the study participants. Data analysis was performed from June 1, 2021 to July 31, 2021. Since the NHIS does not provide personally identifiable information to researchers, information that can identify patients was not used in the analysis. The research design was approved by the Research Deliberation Committee of

Yonsei University Wonju Severance Christian Hospital (IRB No. CR320360).

B. Study subjects

The participants of this study were residents of Sokcho-si, Goseong-gun, Yanggu-gun, and Inje-gun in Gangwon-do, all of whom were enrolled in the health insurance system for 2018 and 2019.

C. Operational definition of disease

The operational definition of disease that we used is based on the 8th Korean Standard Classification of Causes of Diseases, Mental and Behavioral Disorders (F00-F99), Nervous System All Diseases (G00-G99), All Circulatory System Diseases (I00-I99), and Respiratory System Codes (J00-J99) in the categories of main and wounded diseases. Cases that included more than one disease were calculated as one.

D. Statistical analysis

We identified the number of medical users according to region (Yeongdong and Yeongseo), medical utilization (outpatient and hospitalization), period (before and after the wildfire), age (~19, 20–59, and 60–79), and period of medical utilization (≤3 days, ≤1 week, ≤1 month, ≤3 months, and ≤1 year). Analysis was performed by comparing the same periods of a year before and after the wildfire (e.g., April–July 2018 vs. April–July 2019). Since wildfires in spring and autumn are common in Korea due to the influence of westerly winds, temperature, and humidity [3, 27], we thought it is better to compare the previous year of the wildfire we studied and the year after this wildfire, rather than a short-term comparison before and after this wildfire. Therefore, the medical utilization rate was calculated by dividing the number of inpatients from that period by the population during the middle of the year, stratified by city or county/sex/age for the same period. To compare between Yeongdong and Yeongseo, the age-adjusted medical utilization rates in both regions were converted based on the regional standard population proposed by the Korean population census in 2010 [28]. The ratio of the standardized medical utilization rate to the crude medical utilization rate in a standard population was calculated [29]. Concerning the results of the calculated medical utilization rate, logistic regression was performed by region and sex to calculate odds ratio (OR) with reference to the number of hospitalized users under the age of 19 years for each period (April-July 2018 vs. April-July 2019) and sex. The reason for conducting an analysis of hospitalization among various types of

medical services, such as outpatient, hospitalization, and emergency visit, is that emergency medical use can be affected by both the patients themselves and by people around them, such as family members and relatives. Although medical use is greatly affected by geological proximity of medical institutions, hospitalization holds an advantage in that the individual characteristics of users are relatively less affected, compared to outpatient treatment, because the need for hospitalization is highly dependent on the judgment of a medical professional, such as a doctor [30]. Logistic regression was performed considering an increase in medical use per individual as a dependent variable and with age, sex, income, smoking, drinking, and exercise as correction variables. The correction variables were included to adjust for demographic characteristics, socioeconomic status, and health behaviors that affect medical use. In 2019, the Ministry of Health and Welfare of Korea identified the Goseong, Sokcho, Yanggu, and Inje areas, included in our study, as vulnerable regions for emergency medical care. These regions were defined as areas with a vulnerability of 30% or more within an area of the population that could not reach a regional emergency medical center within 1 hour to a local emergency medical center within 30 minutes [31]. Additionally, according to an analysis of the health status of residents of Gangwon-do using data from regional community health surveys, there are minimal differences in smoking, drinking, and obesity rates between Yeongdong and Yeongseo regions [32]. Therefore, we assumed that there was no difference in infrastructure related to medical use in these regions and that age, sex, income, smoking, drinking, and exercise could be considered as factors that could make a difference in medical use between the two

regions. To better understand ORs between age groups in each sex for Yeongdong and Yeongseo regions, we used “medical users under the age of 20 years and before the outbreak of wildfires” as a reference. Thereafter, the number of medical users was categorized only within the relevant period (3 days, 1 week, 1 month, etc.), and logistic regression analysis was performed using these categories. Additionally, when performing logistic regression analysis corrected for confounding variables, the frequency of medical use in the group under 20 years old was relatively low, compared to the other two groups, so it was analyzed as a continuous variable. All data processing and statistical analyses were performed using SAS 9.4 software, and values of $p < 0.05$ were considered significant.

III. RESULTS

A. Demographic characteristics of medical users

Table 1 summarizes the number of medical users by region, period, sex, and age. The mid-year population was 105,068.5 in the Yeongdong area (Goseong and Sokcho) and 53,052.5 in the Yeongseo area (Inje and Yanggu) according to the Population Trend Survey by Statistics Korea in 2018. In 2019, there were 103,108 people in Yeongdong and 51,885 people in Yeongseo. The annual number of outpatients in 2018 was 71,863 in Yeongdong and 37,192 in Yeongseo. In 2019, it was 73,756 and 38,237, respectively. The annual number of hospitalizations in 2018 was 5,644 in Yeongdong and 3,178 in Yeongseo. In 2019, it was 6,237 and 3,378, respectively.

Table 1. Number of medical users by region, period, sex, and age

Age	Yeongdong (N)								Yeongseo (N)							
	outpatient				hospitalization				outpatient				hospitalization			
	Male		Female		Male		Female		Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
3 days																
~19	978	826	932	779	7	4	7	5	614	551	531	544	8	9	2	4
20~59	1,128	938	1,396	1,192	20	22	17	24	568	497	727	652	18	8	15	10
60~79	1,374	1,084	1,801	1,436	29	46	27	29	633	467	737	583	13	18	20	11
1 week																
~19	1,464	1,461	1,414	1,440	15	16	7	11	967	1,018	913	924	16	16	8	10
20~59	1,948	2,200	2,422	2,726	45	56	44	64	965	1,168	1,297	1,367	33	28	32	17
60~79	2,384	2,590	3,245	3,479	61	86	57	73	1,117	1,181	1,277	1,350	30	48	39	34
1 month																
~19	3,192	3,330	3,006	3,209	45	48	51	44	2,055	2,084	1,888	1,965	41	51	28	38
20~59	5,948	6,608	6,932	7,561	240	281	179	233	3,159	3,544	3,738	3,747	113	134	112	87
60~79	6,546	6,710	8,444	8,717	278	336	235	287	3,071	3,195	3,503	3,515	153	165	150	146

Table 1. (Continued.)

Age	Yeongdong (N)								Yeongseo (N)							
	outpatient				hospitalization				outpatient				hospitalization			
	Male		Female		Male		Female		Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
3 months																
~19	4,543	4,893	4,352	4,769	109	164	115	127	2,831	2,893	2,645	2,832	109	105	72	96
20~59	9,997	11,069	11,624	12,463	516	599	430	509	5,472	6,129	6,156	6,193	278	303	263	193
60~79	9,145	9,559	11,230	11,621	583	729	569	659	4,588	4,713	5,001	5,094	350	341	336	341
1 year																
~19	6,389	6,492	6,186	6,344	281	353	278	303	3,723	3,842	3,587	3,778	255	266	176	234
20~59	16,532	17,462	18,683	19,041	1,225	1,348	1,063	1,190	9,147	9,745	9,314	9,384	680	685	560	528
60~79	10,917	11,089	13,156	13,328	1,396	1,534	1,401	1,509	5,551	5,597	5,870	5,927	758	835	749	830

* The Yeongdong area was set in Sokcho, and Goseong, the Yeongseo area was Yanggu, and Inje.

B. Medical utilization rate and age-adjusted medical utilization rate

Table 2 shows the medical utilization rates, which were calculated by dividing the number of hospitalized medical users for each section by the mid-year population. Table 3 shows the resident registration population by region, sex, and age from 2018 to 2019. In the Yeongdong area, the rate of inpatient medical use increased 3 months and 1 year after the fire for both men and women. The rate of inpatient medical use increased in all age groups (except for those aged 19 and under) 3 days, 1 week, and 1 month after the occurrence of the wildfire. In the case of the Yeongseo area, when compared to the Yeongdong area, the use of hospitalized medical care by period, age, and sex after the wildfire differed. Table 4 shows the age-adjusted medical utilization rates. In the case of the wildfire area, the age-adjusted medical utilization rate increased in each period, whereas the control area decreased or showed only a slight increase. In the Yeongdong area, the age-adjusted medical utilization rates increased in both men and women for all periods after the wildfire. The comparative medical utilization ratios for each period were larger in the Yeongdong region than Yeongseo region.

Table 2. Medical utilization rate according to the number of hospitalized medical users (%)

Age	Yeongdong				Yeongseo			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 days								
~19	0.08	0.05	0.08	0.06	0.16	0.19	0.04	0.09
20~59	0.06	0.07	0.06	0.08	0.10	0.05	0.11	0.08
60~79	0.25	0.38	0.20	0.21	0.22	0.29	0.33	0.18
1 week								
~19	0.16	0.18	0.08	0.13	0.32	0.34	0.17	0.22
20~59	0.14	0.18	0.15	0.23	0.18	0.16	0.24	0.13
60~79	0.52	0.71	0.43	0.53	0.51	0.77	0.65	0.55
1 month								
~19	0.48	0.54	0.58	0.53	0.82	1.07	0.59	0.84
20~59	0.73	0.89	0.61	0.82	0.62	0.76	0.85	0.68
60~79	2.39	2.76	1.76	2.08	2.60	2.66	2.48	2.37

Table 2. (Continued.)

Age	Yeongdong				Yeongseo			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 months								
~19	1.17	1.85	1.31	1.52	2.18	2.21	1.52	2.13
20~59	1.58	1.90	1.47	1.80	1.53	1.73	2.00	1.51
60~79	5.02	5.98	4.26	4.77	0.16	0.19	0.04	0.09
1 year								
~19	3.02	3.99	3.17	3.63	5.95	5.50	5.56	5.54
20~59	3.74	4.27	3.63	4.20	5.11	5.60	3.71	5.19
60~79	12.01	12.58	10.50	10.92	3.73	3.91	4.25	4.14

* The medical utilization rate (medical utilization rate = (B/A)*100,

A = the number of people in the country,

B = the number of medical users by section) was calculated using the resident registration population by city / county / province / age for the period.

Table 3. The mid-year population by region, sex, and age (2018-2019)*

	Mid-year population							
	2018				2019			
	Yeongdong		Yeongseo		Yeongdong		Yeongseo	
	Male	Female	Male	Female	Male	Female	Male	Female
Age								
~19	9,314.0	8,769.0	4,993.5	4,738.0	8,857.5	8,346.0	4,746.5	4,505.0
20~59	32,735.0	29,289.5	18,224.0	13,164.5	31,577.0	28,314.5	17,535.0	12,745.5
60~79	11,620.0	13,341.5	5,887.0	6,045.5	12,196.0	13,817.0	6,196.5	6,156.5
Total	53,668.5	51,400.0	29,104.5	23,948.0	52,630.5	50,477.5	28,478.0	23,407.0

* https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1B040M5&conn_path=I2

Table 4. Age-adjusted medical utilization rate according to the number of hospitalized medical users (%)

	Yeongdong				Yeongseo			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 days								
Age-adjusted medical utilization rate	0.094	0.113	0.094	0.106	0.133	0.118	0.145	0.103
Comparative medical utilization ratio		1.195		1.127		0.892		0.708
1 week								
Age-adjusted medical utilization rate	0.204	0.262	0.195	0.271	0.266	0.299	0.314	0.244
Comparative medical utilization ratio		1.281		1.390		1.124		0.779
1 month								
Age-adjusted medical utilization rate	0.938	1.104	0.855	1.029	0.981	1.138	1.147	1.086
Comparative medical utilization ratio		1.177		1.204		1.160		0.947

Table 4. (Continued.)

	Yeongdong				Yeongseo			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 months								
Age-adjusted medical utilization rate	2.027	2.533	2.041	2.382	2.381	2.440	2.664	2.529
Comparative medical utilization ratio		1.250		1.167		1.025		0.949
1 year								
Age-adjusted medical utilization rate	4.884	5.520	5.020	5.535	5.504	5.822	5.901	6.411
Comparative medical utilization ratio		1.130		1.103		1.058		1.086

* The comparative medical utilization ratio = (B/A),

A = Age-adjusted medical utilization rate before the wildfire, B = Age-adjusted medical utilization rate after the wildfire.

C. Odds ratio of hospitalization before and after the wildfire

Limited to inpatient use, ORs were calculated to observe the effect of age on increased healthcare use, with reference to the number of medical users under the age of 19 years for each period and to sex to compare results before and after the wildfire. In the case of the wildfire area, the ORs for medical use increased for the same age groups in each period, whereas the control area decreased or showed only a slight increase (Table 5). In the Yeongdong area, the ORs for medical use increased in both men and women for all periods after the wildfire, except for the group under 19. On the other hand, in the Yeongseo region, the ORs for medical use increased 3 days after the wildfire and 1 year after the wildfire in men over 60 years. The ORs for medical use increased in women only 1 year after the wildfire.

Table 5. ORs (95% CI) for the number of hospitalized medical users by age group for period, region, and sex

Age	Yeongdong OR (95% CI)				Yeongseo OR (95% CI)			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
3 days								
~19	1	0.789 (0.222, 2.807)	1	0.853 (0.270, 2.698)	1	1.246 (0.477, 3.251)	1	1.966 (0.359, 10.778)
20~59	2.834 (1.333, 7.085)*	3.749 (1.513, 9.287)*	1.585 (0.655, 3.836)	2.620 (1.124, 6.108)*	2.723 (1.024, 5.500)*	1.205 (0.449, 3.234)	5.364 (1.221, 23.554)*	3.987 (0.870, 18.276)
60~79	3.373 (1.395, 8.157)*	6.783 (2.884, 15.591)*	1.951 (0.846, 4.497)	2.628 (1.147, 6.024)*	1.538 (0.633, 3.736)	2.886 (1.244, 6.696)*	7.055 (1.642, 30.310)*	4.905 (1.082, 22.230)*
1 week								
~19	1	1.140 (0.554, 2.344)	1	1.544 (0.597, 3.996)	1	0.943 (0.469, 1.896)	1	1.130 (0.434, 2.941)
20~59	2.353 (1.287, 4.303)*	2.593 (1.438, 4.675)*	3.574 (1.605, 7.955)*	4.618 (2.111, 10.104)*	2.005 (1.096, 3.667)*	1.405 (0.756, 2.613)	2.753 (1.263, 6.002)*	1.388 (0.596, 3.229)
60~79	2.607 (1.453, 4.676)*	3.383 (1.916, 5.972)*	3.455 (1.572, 7.594)*	4.128 (1.896, 8.896)*	1.575 (0.853, 2.906)	2.383 (1.344, 4.223)*	3.408 (1.585, 7.327)*	2.810 (1.295. 6.098)

Table 5. (Continued.)

Age	Yeongdong OR (95% CI)				Yeongseo OR (95% CI)			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
1 month								
~19	1	1.127 (0.729, 1.740)	1	0.774 (0.511, 1.173)	1	1.205 (0.795, 1.826)	1	1.284 (0.776, 2.123)
20~59	3.258 (2.307, 4.600)*	3.433 (2.440, 4.831)*	1.491 (1.087 2.047)*	1.780 (1.307, 2.423)*	1.718 (1.196, 2.466)*	1.816 (1.274, 2.587)*	2.009 (1.315, 3.070)*	1.557 (1.007, 2.407)*
60~79	3.429 (2.436, 4.825)*	4.043 (2.833, 5.670)*	1.607 (1.181, 2.188)*	1.902 (1.404, 2.575)*	2.392 (1.687, 3.393)*	2.480 (1.754, 3.507)*	2.872 (1.899, 4.343)*	2.786 (1.840, 4.216)*
3 months								
~19	1	1.437 (1.114, 1.853)*	1	0.980 (0.756, 1.271)	1	0.938 (0.713, 1.236)	1	1.252 (0.915, 1.714)
20~59	2.333 (1.798, 2.775)*	2.342 (1.889, 2.902)*	1.352 (1.096, 1.668)*	1.493 (1.214, 1.836)*	1.277 (1.017, 1.603)*	1.242 (0.992, 1.556)	1.532 (1.173, 2.003)*	1.118 (0.847, 1.475)
60~79	2.758 (2.224, 3.421)*	3.300 (2.669, 4.079)*	1.852 (1.509, 2.273)*	2.073 (1.692, 2.538)*	1.917 (1.536, 2.393)*	1.818 (1.456, 2.271)*	2.410 (1.855, 3.132)*	2.401 (1.849, 3.119)*

Table 5. (Continued.)

Age	Yeongdong OR (95% CI)				Yeongseo OR (95% CI)			
	Male		Female		Male		Female	
	Before	After	Before	After	Before	After	Before	After
1 year								
~19	1	1.214 (1.030, 1.432)*	1	1.089 (0.917, 1.292)	1	1.005 (0.838, 1.204)	1	1.256 (1.025, 1.538)*
20~59	1.659 (1.449, 1.900)*	1.729 (1.511, 1.977)*	1.270 (1.105, 1.459)*	1.395 (1.216, 1.601)*	1.060 (0.912, 1.233)	1.002 (0.862, 1.165)	1.171 (0.983, 1.394)	1.095 (0.918, 1.306)
60~79	2.863 (2.503, 3.276)*	3.098 (2.710, 3.541)*	2.377 (2.074, 2.724)*	2.527 (2.207, 2.893)*	1.947 (1.676, 2.262)*	2.127 (1.834, 2.468)*	2.484 (2.094, 2.946)*	2.726 (2.302, 3.229)*

* p-value < 0.05 : Significant.

D. Logistic regression analysis between the medical use and region

According to multiple logistic regression analysis adjusted for age, sex, income (insurance premium), smoking, drinking, and exercise, the ORs (95% CI) for an increase in medical use in the Yeongdong region, compared to Yeongseo region, at 3 days, 3 months, and 1 year after a wildfire occurred were as follows: 1.026 (1.001 - 1.051), 1.098 (1.084 - 1.111), and 1.029 (1.018 - 1.040), respectively (Table 6). In Tables 2, 3, 4, and 5, age was set into three groups: 0–19 years old, 20–59 years old, and 60–79 years old. For the multiple logistic regression analysis with corrected confounding variables, the frequency of medical use in the group under 20 years was too low, compared to the other two groups, so it was analyzed as a continuous variable (Table 6).

Table 6. Adjusted ORs and 95% CI for an increase in medical use by period, after adjusting for age, sex, income, smoking, drinking, and exercise variables

Variables	OR (95% CI), p-value									
	3 days	p-value	1 week	p-value	1 month	p-value	3 months	p-value	1 year	p-value
Region		0.045*		0.170		<0.001*		<0.001*		<0.001*
Yeongseo	Reference		Reference		Reference		Reference		Reference	
Yeongdong	1.026 (1.001, 1.051)		1.013 (0.995, 1.031)		0.939 (0.927, 0.952)		1.098 (1.084, 1.111)		1.029 (1.018, 1.040)	
Age*		<0.001*		<0.001*		<0.001*		<0.001*		<0.001*
	0.994 (0.993, 0.995)		0.991 (0.990, 0.991)		0.974 (0.973, 0.974)		0.972 (0.972, .973)		0.991 (0.990, 0.991)	
Sex		0.594		0.132		<0.001*		<0.001*		<0.001*
Male	Reference		Reference		Reference		Reference		Reference	
Female	0.993 (0.969, 1.018)		0.986 (0.968, 1.004)		0.947 (0.935, 0.961)		0.948 (0.937, 0.960)		0.898 (0.887, 0.908)	
Income		0.016*		0.029*		<0.001*		<0.001*		<0.001*
	1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)	

Table 6. (Continued.)

Variables	OR (95% CI), p-value									
	3 days	p-value	1 week	p-value	1 month	p-value	3 months	p-value	1 year	p-value
Smoking		<0.001*		0.079		<0.001*		<0.001*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	0.885 (0.854, 0.917)		0.978 (0.953, 1.003)		1.106 (1.087, 1.126)		1.112 (1.094, 1.130)		1.251 (1.234, 1.268)	
Alcohol		0.004*		<0.001*		<0.001*		<0.001*		0.096
NO	Reference		Reference		Reference		Reference		Reference	
YES	0.958 (0.931, 0.986)		1.064 (1.042, 1.086)		0.968 (0.954, 0.983)		0.971 (0.958, 0.984)		0.990 (0.979, 1.002)	
Exercise		<0.001*		<0.001*		<0.001*		0.006*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	0.938 (0.916, 0.959)		0.947 (0.931, 0.962)		0.971 (0.959, 0.983)		1.016 (1.004, 1.027)		1.045 (1.035, 1.056)	

* Age is adjusted as a continuous variable

E. Logistic regression analysis between the medical use and region according to the presence or absence of an underlying disease

Additional logistic regression analysis separately according to the presence or absence of an underlying disease indicated that ORs for medical use in the Yeongdong region, compared to Yeongseo region, among individuals with an underlying disease increased significantly at 1 week, 1 month, 3 months, and 1 year after the wildfire as follows: 1.153 (1.013–1.313), 1.142 (1.067–1.223), 1.422 (1.362–1.485), and 1.112 (1.082–1.143), respectively (Table 7). The ORs for an increase in medical use in the group without underlying disease were also significantly increased at 3 days, 1 week, 3 months, and 1 year after the onset of the wildfire 1.045 (1.020–1.071), 1.046 (1.028–1.065), 1.108 (1.096–1.120), and 1.079 (1.069, 1.090), respectively (Table 8). The ORs for each period were larger in the group with underlying diseases than in the group without underlying diseases.

Table 7. Adjusted ORs and 95% CI for an increase in medical use by period, after adjusting for age, sex, income, smoking, drinking, and exercise variables (with underlying diseases)

Variables	OR (95% CI), p-value									
	3 days	p-value	1 week	p-value	1 month	p-value	3 months	p-value	1 year	p-value
Region		0.552		0.032*		<0.001*		<0.001*		<0.001*
Yeongseo	Reference		Reference		Reference		Reference		Reference	
Yeongdong	1.065 (0.865, 1.311)		1.153 (1.013, 1.313)		1.142 (1.067, 1.223)		1.422 (1.362, 1.485)		1.112 (1.082, 1.143)	
Age*		<0.001*		0.166		0.039*		<0.001*		<0.001*
	0.982 (0.973, 0.991)		1.004 (0.998, 1.010)		0.997 (0.994, 1.000)		1.004 (1.002, 1.005)		1.003 (1.002, 1.004)	
Sex		0.019*		<0.001*		0.660		0.614		0.087
Male	Reference		Reference		Reference		Reference		Reference	
Female	0.792 (0.652, 0.961)		1.305 (1.140, 1.494)		1.016 (0.946, 1.091)		0.989 (0.946, 1.034)		1.025 (0.996, 1.054)	

Table 7. (Continued.)

Variables	OR (95% CI), p-value									
	3 days	p-value	1 week	p-value	1 month	p-value	3 months	p-value	1 year	p-value
Income		<0.001*		<0.001*		0.892		<0.001*		<0.001*
	1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)	
Smoking		<0.001*		<0.001*		<0.001*		<0.001*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	1.782 (1.320, 2.406)		2.563 (2.132, 3.080)		1.257 (1.147, 1.377)		1.160 (1.096, 1.228)		1.138 (1.098, 1.178)	
Alcohol		0.533		0.814		0.085		<0.001*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	1.088 (0.834, 1.419)		0.980 (0.830, 1.158)		1.075 (0.990, 1.167)		1.109 (1.054, 1.167)		1.090 (1.056, 1.125)	
Exercise		0.492		0.233		<0.001*		0.044*		0.370
NO	Reference		Reference		Reference		Reference		Reference	
YES	1.071 (0.881, 1.302)		0.923 (0.808, 1.053)		1.165 (1.090, 1.246)		1.043 (1.001, 1.086)		0.988 (0.963, 1.014)	

Table 8. Adjusted ORs and 95% CI for an increase in medical use by period, after adjusting for age, sex, income, smoking, drinking, and exercise variables (without underlying diseases)

Variables	OR (95% CI), p-value									
	3 days	p-value	1 week	p-value	1 month	p-value	3 months	p-value	1 year	p-value
Region		<0.001*		<0.001*		0.050*		<0.001*		<0.001*
Yeongseo	Reference		Reference		Reference		Reference		Reference	
Yeongdong	1.045 (1.020, 1.071)		1.046 (1.028, 1.065)		0.988 (0.976, 1.000)		1.108 (1.096, 1.120)		1.079 (1.069, 1.090)	
Age*		<0.001*		<0.001*		<0.001*		<0.001*		<0.001*
	0.997 (0.996, 0.998)		0.995 (0.995, 0.996)		0.990 (0.990, 0.991)		0.993 (0.993, 0.993)		1.002 (1.002, 1.002)	
Sex		0.768		0.376		0.209		<0.001*		<0.001*
Male	Reference		Reference		Reference		Reference		Reference	
Female	1.004 (0.979, 1.029)		0.992 (0.974, 1.010)		1.008 (0.995, 1.021)		1.049 (1.037, 1.061)		1.021 (1.011, 1.031)	

Table 8. (Continued.)

Variables	OR (95% CI), p-value									
	3 days	p-value	1 week	p-value	1 month	p-value	3 months	p-value	1 year	p-value
Income		<0.001*		0.192		0.002*		0.068		<0.001*
	1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)		1.000 (1.000, 1.000)	
Smoking		<0.001*		<0.001*		<0.001*		<0.001*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	0.867 (0.836, 0.898)		0.948 (0.925, 0.973)		1.045 (1.027, 1.063)		1.047 (1.032, 1.062)		1.101 (1.087, 1.115)	
Alcohol		0.044*		<0.001*		<0.001*		<0.001*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	0.971 (0.943, 0.999)		1.038 (1.016, 1.059)		0.938 (0.925, 0.951)		0.957 (0.945, 0.968)		1.024 (1.014, 1.035)	
Exercise		<0.001*		<0.001*		0.002*		<0.001*		<0.001*
NO	Reference		Reference		Reference		Reference		Reference	
YES	0.944 (0.923, 0.966)		0.948 (0.932, 0.964)		1.018 (1.006, 1.030)		1.023 (1.013, 1.034)		1.038 (1.029, 1.048)	

IV. DISCUSSION

This study identified changes in medical utilization for areas affected by wildfires in Gangwon-do, Korea, in April 2019. It was confirmed that medical use was greater than that in a non-affected areas adjacent to the wildfire-affected areas.

In the case of Yeongdong, the wildfire-damaged area, OR values for medical use increased in the same age group in each period, while it decreased or slightly increased in the control area. In the case of men in both the Yeongdong and Yeongseo regions, the ORs for medical use increased as age increased in each period after the fire. In the case of women, the results were similar to those of men, except for the 20–60-year-old group in the Yeongdong region (Table 5).

From the logistic regression analysis with adjustment for confounding variables (Table 6), the OR value increased most significantly in Yeongdong compared to Yeongseo after 3 months (OR = 1.098, 95%, CI = 1.084–1.111). In addition, the OR value of the group with underlying diseases at 3 months after the fire was 1.422 (95%, CI = 1.362–1.485). This was larger than the OR value of 1.108 (95%, CI = 1.096–1.120) in the group without underlying diseases (Tables 7 and 8).

These results are consistent with those of previous studies on the health effects of wildfires. In a study by Morgan et al., for every 10 μg/m^3 increase in PM_{10} concentration during a wildfire, the hospitalization rate for all respiratory diseases increased by 1.24% (Lag 0, 95%, CI: 0.22–2.27%), that for chronic obstructive pulmonary diseases increased by 3.80% (Lag 2, 95%, CI: 1.40–6.26%), and that for asthma increased by 5.02% (Lag 0, 95%, CI: 1.77–8.37%) [33]. In a 2002 study examining the health effects of wildfires in Quebec, Canada (in the Medicare population of the Northeastern United States and the mid-Atlantic), hospitalizations for when airborne smoke was present were 49.6% (95%, CI: 29.8–72.3%) and 64.9% (95%, CI: 44.3~88.5) for respiratory and cardiovascular diagnoses, respectively, suggesting that smoke can affect the health of people thousands of kilometers away from a fire [34]. Liu et al., Youssouf et al., and Reid et al. reported through a systematic literature review that a strong association exists between asthma, chronic obstructive pulmonary disease (COPD), bronchitis, and exacerbation of pneumonia in a group exposed to wildfire smoke [9, 35, 36].

Several epidemiological studies have reported that exposure to wildfire smoke contributes to the exacerbation of asthma and chronic obstructive pulmonary disease. Martin et al. (2013) did not find any association with cardiovascular disease hospitalization, but confirmed an increase in hospitalization due to exacerbation of chronic lower respiratory tract diseases, such as asthma and COPD, and the possibility of cardiovascular side effects due to plant fire smoke exposure [37]. Elliott et al. (2013) reported a 6% increase in the use of drugs to alleviate exacerbations of chronic respiratory disease during wildfire

smoke exposure in British Columbia, representing an increase in COPD or asthma exacerbations [38].

Since 2000, the largest number of large-scale wildfires in Korea by region has occurred in Gangwon-do, followed by Gyeongsangbuk-do and Jeollabuk-do. The main causes of these results are coniferous forests, such as pine trees, which are vulnerable to high temperatures and dry weather conditions in spring in Gangwon-do, typhoon-class strong winds, and large-scale wildfires [27]. In contrast, the proportions of the older adult in Gangwon-do and Gyeongsangbuk-do are 21.2% in Gangwon-do and 22.2% in Gyeongsangbuk-do as of June 2021, which is a super-aged region [39]. In a 2017 study, Liu et al. observed that the risk of hospitalization for respiratory diseases increases with age during wildfires in older adults in the Western United States [40]. Older adults and people with underlying diseases are sensitive groups that may be at higher risk; hence, a wildfire can cause many serious health side effects. Finally, the Gangwon-do region, as the subject of this study, is also one of the poorest in Korea, with an annual per capita income of 19,174,000 won per city and province [41]. A particulate matter-related health impact survey for large wildfires in northern California observed a linear increase in the risk of hospitalization for asthma (relative risk=1.07, 95% CI= 1.05-1.10 per 5ug/m^3 increase) in the summer of 2008, as well as a greater increase in respiratory emergency department visits for lower median incomes [42]. Another study reported that during the 2008 North Carolina fires at the Lake Pocosin National Wildlife Refuge increased emergency room visits for asthma and congestive heart failure were associated with poor socioeconomic

conditions [15]. These socioeconomic characteristics of Gangwon-do can make the health effects of wildfires larger in this study, although the results of adjusting for income and age also showed significant results.

This study has several limitations. First, the national health insurance data are documented as globally excellent data in terms of scale and diversity, but excludes foreigners and people whose place of residence is unclear. In addition, since not all people with health problems use hospitals, they cannot receive health insurance benefits, and as a result, if there are many cases where people with health disorders do not use medical institutions or are not treated, the total number of people with health problems may be underestimated. In addition, even when visiting a medical institution, misclassification of diseases or coding errors related to diagnosis names may occur. Second, in this study, the following diseases, including mental and behavioral disorders, diseases of the nervous system, circulatory system, and respiratory system were not analyzed separately. There is a limitation in not being able to analyze respiratory diseases, cardiovascular diseases, mental diseases, and neurological diseases as individual disease groups. Although there is little disagreement about the occurrence and aggravation of respiratory diseases due to exposure to wildfire smoke, there is controversy about the occurrence and worsening of cardiovascular, psychiatric, and neurological diseases due to exposure to wildfire smoke. The analysis was conducted only to observe changes in overall medical use, so it was not possible to discern which disease group caused the increase in medical use. As the overall increase in medical use due to wildfires has been confirmed, additional research on

individual disease groups is needed in the future. Future studies should examine the diseases that increased the most due to the occurrence of wildfires. Finally, the effects of a single wildfire in Goseong and Sokcho, the target regions of this study, may not represent the effects of other wildfires sufficiently. Sixteen wildfires occurred in Goseong, Sokcho, Yanggu, and Inje areas in Gangwon-do, Korea from April 4, 2018, to December 31, 2019. The health effects of extensive wildfire smoke exposure were investigated in the wildfire that occurred in Goseong and Sokcho on April 4, 2019, which was the fourth largest wildfire in Korea based on the damage area at the time of occurrence [3]. It was difficult to verify health data because the larger scale wildfires occurred in the late 1990s and early 2000s. On the other side, the east coast of Gangwon-do, the areas affected by the wildfire, were declared a special disaster zone by the government two days after the wildfire occurred. In special disaster zones, medical expenses are exempted or discounted if selected as disaster victims from self-employed insurer in the National Health Insurance for up to 6 months. Expansion of Medicaid beneficiaries can lead to increased medical use due to moral hazard and adverse selection [43]. In addition, wildfires are difficult to study because it is difficult to distinguish emissions, and there are many uncertainties in quantitative exposure assessments for individual exposure. Therefore, even in this study, it was not possible to directly measure health effects through accurate exposure assessments for participants.

Despite these limitations, the present study has several advantages. Korea's National Health Insurance provides the most reliable information on medical use in

wildfire-affected areas with large-scale data, as it is mandatory for all medical providers and citizens to subscribe.

V. CONCLUSION

This study found that the use of medical care in a wildfire-affected area significantly increased the use of hospitalization, compared to a control area that possessed similar demographic characteristics. A systematic study on the health impact of the population group exposed to wildfires and a study on an approach system for sensitive groups are both necessary. This study hopes to serve as a basis for preparing a plan to provide appropriate medical care to residents when establishing a wildfire response system in the future.

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국 문 요 약

한국 산불연기 노출이 의료이용에 미치는 영향

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연구배경 및 목적

한국의 강원도 동부 지역은 특징적인 지형과 기후로 인해 대규모 산불이 발생하는 경우가 많다. 그동안 대규모 산불이 건강에 미치는 영향에 대한 국내 연구가 거의 없었다. 본 연구의 목적은 2019년 한국 강원도 지역에서 발생한 산불을 전후하여 산불피해지역과 인접한 비피해지역의 의료이용 차이를 분석하는 것이다.

대상 및 방법

국민건강보험공단 의료보험자료를 이용하여 산불피해지역(영동)과 인접한 비피해지역(영서) 주민의 의료이용률을 산정한다. 개인당 의료이용 증가량을 종속변수로 하고 연령, 성별, 소득, 흡연여부, 음주여부, 운동여부를 보정변수로 하여 로지스틱회귀분석을 실시하였다.

결과

산불피해지역(영동)이 인접한 비피해지역(영서)에 비해 산불 발생 3일, 3개월, 1년의 시간이 경과한 시점에서 의료이용 교차비(odds ratio, OR)가 유의하게 증가하였다. OR(95% CI)은 각각 1.026(1.001 – 1.051), 1.098(1.084 – 1.111) 및 1.029(1.018 – 1.040)이다.

결론

본 연구의 결과, 산불 피해지역 주민에서 인접한 비피해지역 주민과 비교하여 의료이용이 증가함을 확인하였다. 이것은 한국에서 산불과 입원 의료이용과의 관계에 대한 최초의 연구이다.

핵심되는 말: 산불, 건강영향, 의료이용, 입원.