INTRODUCTION

Suicide is a worldwide problem. According to WHO statistics, 800,000 suicides occurred in 2015 [1]. Suicide rate of South Korea is 28.7 per 100,000 people, 2.4 times the OECD average suicide rate, the highest among OECD countries since 2003 [2]. According to Bertolote et al. [3], depression is the overt cause of suicide worldwide and accounts for 30%. However, in addition to psychiatric disorders such as depressive disorder, various causes are involved in suicide. Socioeconomic, genetic, environmental and bioclimatic factors can lead to suicide [4-8]. Among bio-climatic component, particularly in terms of meteorology, previous studies have reported that suicide shows seasonality. And many studies have shown that suicide rates peak in spring and early summer [7,9-11]. These meteorological factors include temperature, sunlight, solar radiation, air pressure, precipitation, humidity, and air-pollutants [12-14].

Recent studies have focused on the link between the climate factor and the neuroendocrine system [15,16]. Serotonin is a neurotransmitter that affects mood particularly. Low levels of serotonin cause depression and impulsivity, which in turn, can lead to suicidal behavior [9,17,18]. In addition, changes in serotonin 1-A receptor which attached to limbic system are controlled by light and have an effect on mood [19]. As mentioned previously, serotonin is affected by climate factors like sunlight and environmental heat [9]. Previous research reported that sunshine also affects suicidal behavior [20-22] by affecting the action of hormones such as serotonin and melatonin [23-25]. Preti and Miotto [9] mentioned that temperature, solar radiation and duration of sunlight had considerable correlation with monthly suicide attempts. In addition, there have been increasing reports that air-pollutants, seasonal changes and suicide are related to each other [26,27].

The previous reports on the seasonality of suicide is consistent and is still controversial. Therefore, this study was conducted to find out the factors affecting the number of suicide attempts according to the season.
Climate and Suicide Attempts

Study design and participants
This study is a longitudinal study and data were collected retrospectively. Information on the number of patients who visited the emergency room (ER) in a university affiliated hospital from March 2006 to December 2017 due to suicide attempt were obtained via medical chart review. A total of 2,181 suicide attempters have visited ER during the period. Data on the climatic factors and air-pollution factors were downloaded from the webpage of Korea Meteorological Administration. This study was approved by the Institutional Review Board (IRB) of Konkuk University Hospital, and written informed consent was waived (approval number: KUMC 201910026).

Measurements
Information on climate factors were obtained from the Korea Meteorological Administration. We decided to identify two types of variables: air-pollutants and weather-related factors. Air pollutants include particulate matter which was less than 10 μm in size (PM₁₀), ozone (O₃), nitrogen dioxide (NO₂), carbon monoxide (CO), and sulfur dioxide (SO₂). Weather-related elements contains daily mean temperature, maximum and minimum temperature, and diurnal temperature range. Here, diurnal temperature range is the difference between daily maximum and daily minimum temperature [28]. In addition, mean atmospheric pressure, mean vapor pressure, relative humidity, sunshine hours, amount of sunshine, amount of rainfall, and amount of snowfall were evaluated as weather-related factors that might be affect suicide attempts.

Statistical analysis
Number of suicide attempts were measured weekly within the study period and classified according to the four seasons. They were divided into four groups: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

The following analysis was conducted to investigate the relationship between the number of suicide attempts per week and the climate according to the season. One-way analysis of variance (ANOVA) was used to compare weekly suicide attempts and climate factors measured with continuous variables by four seasons. Pearson’s correlation analysis was conducted to determine whether the number of suicide attempts per week was related to various climate factors. And then stepwise multiple regression analysis was carried out to find the most influential variable among the various climate factors for each season. In correlation analysis, factors that showed a significant correlation with the number of suicide attempts per week were entered as independent variables in regression analysis. All data analyses were performed using the Statistical Package for the Social Sciences, version 17 (SPSS Inc., Chicago, IL, USA). Statistical significance level was defined at p<0.05.

RESULTS

The number of suicide attempts for each season was spring (n=554), summer (n=576), autumn (n=558), and winter (n=493), and it did not show significant difference between four seasons. On the other hand, climatic and air-pollution factors appeared differently depending on the season. Among the air-pollutants, the level of PM₁₀ and O₃ generated in spring were highest (p<0.001). The above mentioned contents are exhibited in Table 1.

As a result of correlation analysis, there were differences in factors related to weekly suicide attempts by season. In spring, diurnal temperature range and sunshine hours (r=0.166, p=0.038) were positively correlated with weekly suicide attempts. O₃ (r=0.162, p=0.044), daily mean temperature (r=0.163, p=0.042), and maximum temperature (r=0.174,
p=0.030) showed significantly correlation with weekly suicide attempts during autumn. Meanwhile, mean temperature (r=0.223, p=0.007), maximum temperature (r=0.239, p=0.004), and minimum temperature (r=0.198, p=0.016) were significantly correlated with weekly suicide attempts in winter (Table 2). However, no climatic factor was associated with weekly suicide attempts in summer.

The results of multiple regression analysis were as follows. In spring, the number of weekly suicide attempts was positively associated with the diurnal temperature range (β=0.231, p=0.025). However, the maximum temperature was related to the number of suicide attempts per week in autumn and winter (Table 3).

**DISCUSSION**

The purpose of this study was to investigate the factors affecting weekly suicide attempts by season. There was no significant difference in suicide attempts between seasons in this study. However, different climate-related factors were associated with the number of suicide attempts according to the season. The diurnal temperature range in spring, and the maximum temperature in autumn and winter were related to the number of weekly suicide attempts. On the other hand, among air-pollutants, O₃ was associated with suicide attempts in autumn in correlation analysis, but not in regression analysis.

Results of previous studies suggested that temperature is highly associated with various psychiatric illnesses. Milstein et al. [29] reported that the prevalence of mood disorder increased as the difference between daily maximum and minimum temperatures was getting larger in spring and autumn. According to previous studies, sudden changes in climate, especially temperature and humidity, have been associated with increased the number of suicides [30,31]. Like seasonality of suicide attempts, the seasonal variation of mood disorders have been reported in several literatures. Exacerbation of mood disorders results in more frequent electro-con-vulsion therapy use, hospitalization, and poorer depression scores, especially in spring [9,32-34]. Magnusson [35] also said that the number of suicides and consultation due to depression, and the prescription of antidepressants depend on the seasons. Therefore, it may be assumed that sudden changes of temperature, such as in the spring, can lead to exacerbation of mood disorders and increase the number of suicides.

Many studies report that suicide attempts tend to increase as the temperature warms up. In a study conducted in England and Wales, the suicide rate increased by 3.8% for every 1°C rise in average temperature above 18°C [36]. Previous studies mentioned that as the temperature rose, suicidal behaviors were increased because the excitability of the central nervous system extended [37,38]. Moreover, suicide attempts increased because higher temperature caused impulsivity and disinhibition [26,39], and this was related to serotonin neurotransmitter [40-43]. These studies are consistent with our findings that maximum temperatures in autumn and winter influenced suicide attempts.

This study did not show a link between suicide attempts and climate in the summer. Several assumption can be drawn to explain this. First, vacation periods are usually in summer in Korea and lots of outdoor activity favors how weather. Therefore, high temperature in summer might cause different influence to individuals according to what they do in summer. Second, the effect of high temperature on mood and suicide behavior may show ceiling effect in summer because of its high average temperature. Further studies are needed to give clear link between climate and suicide in summer.

Previous studies have generally stated that in spring, O₃ concentrations rise high [44,45], and O₃ levels can increase to 45% [46]. Biermann et al. [26] reported that O₃ might cause neurotransmitters imbalances such as serotonin and dopamine, leading to depression and suicidality. Two previous studies reported that serum cortisol level was elevated when exposed to O₃, which can make depression worse [47,48]. In addition, O₃ have an effect on the immune system and can cause impulsive behavior, which increases the suicides [26,49-52]. Biermann et al. [26] reported that the association between O₃ level and suicide rates did not show seasonality. However, most of those results were not reported in the consideration of climatic factors other than air-pollutants. In this study, we analyzed both air-pollution factors and climate-related factors and showed that air-pollutions might not affect suicide behavior as much as climatic factors do. Besides, there was a significant positive correlation between diurnal temperature range and O₃ concentration in spring in our study, which suggest that air-pollution are highly related to the change in climate.

**Table 2. Correlation between weekly suicide attempts and climate variables**

| Season  | Climate variable                  | R     | p-value |
|---------|----------------------------------|-------|---------|
| Spring  | Diurnal temperature range        | 0.179 | 0.025   |
|         | Sunshine hours                   | 0.166 | 0.038   |
| Autumn  | O₃                               | 0.162 | 0.044   |
|         | Mean temperature                 | 0.163 | 0.042   |
|         | Maximum temperature              | 0.174 | 0.030   |
| Winter  | Mean temperature                 | 0.223 | 0.007   |
|         | Maximum temperature              | 0.239 | 0.004   |
|         | Minimum temperature              | 0.198 | 0.016   |

**Table 3. Climate factors affecting weekly suicide attempts**

| Season  | Climatic factor                  | Beta  | Standardized beta | p-value | R²  |
|---------|----------------------------------|-------|-------------------|---------|-----|
| Spring  | Diurnal temperature range        | 0.231 | 0.179             | 0.025   | 0.032|
| Autumn  | Maximum temperature              | 0.057 | 0.174             | 0.030   | 0.030|
| Winter  | Maximum temperature              | 0.119 | 0.239             | 0.004   | 0.057|
Over the past 20 years, several studies have reported the tendency to increase suicide in spring [53,54], and the relationship between suicide and seasonality [14,53,55]. Factors such as solar radiation [14] and delayed circadian rhythms were suggested to be associated with increased suicide rates in spring [11]. However, suicide attempts did not increase in spring of this study. Small numbers of subjects and the regional characteristics may have caused this result since the present study was conducted in a single institution.

The limitations of this study come as follows. First of all, because the patients visited in a single institution ER, the sample was relatively small. Therefore, it is possible that sample bias could have occurred. Second, we did not include other factors such as gender, age and the presence of psychiatric disorders that could affect suicide attempts. Third, we divided a year into four seasons in this study. It may not reflect seasonal differences adequately since there has been climate changes in Korea.

However, we collected data on suicide attempt, climate and air-pollution for a relatively long period, and showed that the effect of climate and air-pollution on suicide shows seasonal variation. Multi-center studies that cover wider regional area are need to clarify these associations.

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None

Conflicts of Interest
The authors have no potential conflicts of interest to disclose.

Author Contributions
Conceptualization: Hong Jun Jeon. Data curation: Seung Beom Yang. Formal analysis: Hong Jun Jeon, Jin Shin. Investigation: Hong Jun Jeon, Doo Heum Park. Writing—original draft: Hong Jun Jeon, Seung Beom Yang, Jin Shin. Writing—review & editing: Hong Jun Jeon, Doo Heum Park.

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REFERENCES
1. World Health Organization. Prevention of suicidal behaviours: a task for all. Available at: https://www.who.int/mental_health/prevention/suicide/background/en/. Accessed April 1, 2020.
2. OECD. Data: suicide rates (indicator) 2016. Available at: https://data.oecd.org/healthstat/suicide-rates.htm. Accessed April 1, 2020.
3. Bertolote J, Fleischmann A, De Leo D, Wasserman D. Suicide and seasonality. Acta Psychiatr Scand 2003;110(Suppl 413):1-43.
4. Appleby L, Cooper J, Amos T, Faragher B. Psychological autopsy study of suicides by people aged under 35. Br J Psychiatry 1999;175:168–174.
5. Stack S. Suicide: a 15-year review of the sociological literature. Part I: cultural and economic factors. Suicide Life Threat Behav 2000;30:145–162.
6. Ajdacic-Gross V, Wang J, Bopp M, Eich D, Rössler W, Gutzwiller F. Are seasonalities in suicide dependent on suicide methods? A reappraisal. Soc Sci Med 2003;57:1173–1181.
7. Chew KS, Mc Cleary R. The spring peak in suicides: a cross-national analysis. Soc Sci Med 1995;40:223–230.
8. Asberg M, Träskman L, Thorén P. 5-HIAA in the cerebrospinal fluid. A biochemical suicide predictor? Arch Gen Psychiatry 1976;33:1193–1197.
9. Preti A, Miotto P. Seasonality in suicides: the influence of suicide method, gender and age on suicide distribution in Italy. Psychiatry Res 1998;81:219-231.
10. Partonen T, Haukka J, Nevanlinna H, Lönnqvist J. Analysis of the seasonal pattern in suicide. J Affect Disord 2004;81:133–139.
11. Lee HJ. Circadian misalignment and bipolar disorder. Chronobiol Med 2019;1:132-136.
12. Deisenhammer EA. Weather and suicide: the present state of knowledge on the association of meteorological factors with suicidal behaviour. Acta Psychiatr Scand 2003;108:402–409.
13. Preti A, Miotto P, De Coppi M. Season and suicide: recent findings from Italy. Crisis 2000;21:59–70.
14. Jee HJ, Cho CH, Lee YJ, Choi N, An H, Lee HJ. Solar radiation increases suicide rate after adjusting for other climate factors in South Korea. Acta Psychiatr Scand 2017;135:219–227.
15. De Vriese SR, Christophe AB, Maes M. In humans, the seasonal variation in polyunsaturated fatty acids is related to the seasonal variation in violent suicide and serotonergic markers of violent suicide. Prostaglandins Essent Fatty Acids 2004;71:13–18.
16. Linkowski P, Martin F, De Maertelaer V. Effect of some climatic factors on violent and non-violent suicides in Belgium. J Affect Disord 1992;25:161–166.
17. Cocco EF. Central serotonin and impulsive aggression. Br J Psychiatry Suppl 1989;155:52–62.
18. Brown GL, Linnola MJ. CSF serotonin metabolite (5-HIAA) studies in depression, impulsivity, and violence. J Clin Psychiatry 1990;51 Suppl:3–43.
19. Spindellegger C, Stein P, Wada SK, Fink M, Mitterhauser M, Moser U, et al. Light-dependent alteration of serotonin-1A receptor binding in cortical and subcortical limbic regions in the human brain. World J Biol Psychiatry 2012;13:413–422.
20. Christodoulou C, Douzenis A, Papadopoulos FC, Papadopoulou A, Bouras G, Gournellis R, et al. Suicide and seasonality. Acta Psychiatr Scand 2012;125:127–146.
21. Tihonien I, Räisänen P, Hakkio H. Seasonal variation in the occurrence of homicide in Finland. Am J Psychiatry 1997;154:1711–1714.
22. Lambert GW, Reid C, Kaye DM, Jennings GL, Esler MD. Effect of sunlight and season on serotonin turnover in the brain. Lancet 2002;360:1840–1842.
23. Coimbra DG, Pereira E Silva AC, de Sousa-Rodrigues CF, Barbosa FT, de Siqueira Figueredo D, Araújo Santos J, et al. Do suicide attempts occur more frequently in the spring too? A systematic review and rhythmic analysis. J Affect Disord 2016;196:125–137.
24. Vyssoki B, Praschak-Rieder N, Sonneck G, Blümel V, Willeit M, Kasper S, et al. Effects of sunshine on suicide rates. Compr Psychiatry 2012;53:535–539.
25. Petridou E, Papadopoulos FC, Frangakis CE, Skalkidou A, Trichopoulos D. A role of sunshine in the triggering of suicide. Epidemiology 2002;13:106–109.
26. Biermann T, Stillanakis N, Bleich S, Thurow N, Koobhuber J, Reulbach U. The hypothesis of an impact of ozone on the occurrence of completed and attempted suicides. Med Hypotheses 2009;72:338–341.
27. Glaedke A, Rymaszewska J, Zatowski T. Impact of air pollution on depression and suicide. Int J Occup Med Environ Health 2018;31:711–721.
28. Holopainen J, Haukka J, Nevanlinna H, Lönnqvist J. Analysis of the seasonalities in suicide dependent on suicide methods? A reappraisal. Soc Sci Med 2003;57:1173–1181.
29. Milstein V, Small JG, Shelbourne D, Willeit M, Kasper S, et al. Effects of sunshine on suicide rates. Compr Psychiatry 2012;53:535–539.
30. Petridou E, Papadopoulos FC, Frangakis CE, Skalkidou A, Trichopoulos D. A role of sunshine in the triggering of suicide. Epidemiology 2002;13:106–109.
33. Morken G, Lilleeng S, Linaker OM. Seasonal variation in suicides and in admissions to hospital for mania and depression. J Affect Disord 2002;69:39-45.
34. Goodwin FK, Jamison KR. Manic-depressive illness: bipolar disorders and recurrent depression. 2nd ed. New York: Oxford University Press; 2007.
35. Magnusson A. An overview of epidemiological studies on seasonal affective disorder. Acta Psychiatr Scand 2000;101:176-184.
36. Page LA, Hajat S, Kovats RS. Relationship between daily suicide counts and temperature in England and Wales. Br J Psychiatry 2007;191:106-112.
37. Dixon KW, Shulman MD. A statistical investigation into the relationship between meteorological parameters and suicide. Int J Biometeorol 1983;27:93-105.
38. Ajdacic-Gross V, Bopp M, Ring M, Gutzwiller F, Rossler W. Seasonality in suicide—a review and search of new concepts for explaining the heterogeneous phenomena. Soc Sci Med 2010;71:657-666.
39. Anderson CA. Temperature and aggression: ubiquitous effects of heat on occurrence of human violence. Psychol Bull 1989;106:74-96.
40. Akkaya-Kalayci T, Vyssoki B, Winkler D, Willeit M, Kapusta ND, Dorffner G, et al. The effect of seasonal changes and climatic factors on suicide attempts of young people. BMC Psychiatry 2017;17:365.
41. Kim Y, Kim H, Honda Y, Guo YL, Chen BY, Woo JM, et al. Suicide and ambient temperature in East Asian countries: a time-stratified case-crossover analysis. Environ Health Perspect 2016;124:75-80.
42. Luykx JJ, Bakker SC, van Geloven N, Eijkemans MJ, Horvath S, Lentjes E, et al. Seasonal variation of serotonin turnover in human cerebrospinal fluid, depressive symptoms and the role of the 5-HTTLPR. Transl Psychiatry 2013;3:e311.
43. Mann JJ. The serotonergic system in mood disorders and suicidal behaviour. Philos Trans R Soc Lond B Biol Sci 2013;368:20120537.
44. Kajii Y, Someno K, Tamimoto H, Hirokawa J, Akimoto H, Katuno T, et al. Evidence for the seasonal variation of photochemical activity of tropospheric ozone: continuous observation of ozone and CO at Hoppo, Japan. Geophys Res Lett 1998;25:3505-3508.
45. Tamimoto H, Sawa Y, Matsueda H, Uno I, Ohara T, Yamaji K, et al. Significant latitudinal gradient in the surface ozone spring maximum over East Asia. Geophys Res Lett 2005;32:L21805.
46. Yienger JJ, Klonecki AA, Levy H II, Mexim WJ, Carmichael GR. An evaluation of chemistry’s role in the winter-spring ozone maximum found in the northern midlatitude free troposphere. J Geophys Res Atmos 1999;104:3655-3667.
47. Maes M, Scharpé S, Verkerk R, D’Hondt P, Peeters D, Cosyns P, et al. Seasonal variation in plasma 5-tryptophan availability in healthy volunteers. Relationships to violent suicide occurrence. Arch Gen Psychiatry 1995;52:937-946.
48. Thomson EM, Pal S, Guenette J, Wade MG, Atlas E, Holloway AC, et al. Ozone inhalation provokes glucocorticoid-dependent and -independent effects on inflammatory and metabolic pathways. Toxicol Sci 2016;152:17-28.
49. Pereyra-Muñoz N, Rugejio-Vargas C, Angoa-Pérez M, Borgenio-Pérez G, Rivas-Arancibia S. Oxidative damage in substantia nigra and striatum of rats chronically exposed to ozone. J Chem Neuroanat 2006;31:114-123.
50. Bach H, Huang YY, Underwood MD, Dwork AJ, Mann JJ, Arango V. Elevated serotonin and 5-HIAA in the brainstem and lower serotonin turnover in the prefrontal cortex of suicides. Synapse 2014;68:127-130.
51. Chatzittofis A, Nordström P, Hellström C, Arver S, Åsberg M, Jokinen J. CSF 5-HIAA, cortisol and DHEAS levels in suicide attempters. Eur Neuropsychopharmacol 2013;23:1280-1287.
52. Bach-Mizrachi H, Underwood MD, Tint A, Ellis SP, Mann JJ, Arango V. Evoked expression of tryptophan hydroxylase-2 mRNA at the neuronal level in the dorsal and median raphe nuclei of depressed suicides. Mol Psychiatry 2006;13:507-513.
53. Lee HJ, Kim L, Joe SH, Suh KY. Effects of season and climate on the first manic episode of bipolar affective disorder in Korea. Psychiatry Res 2002;113:151-159.
54. Cho CH, Lee HJ. Why do mania and suicide occur most often in the spring? Psychiatry Investig 2018;15:232-234.
55. Kim JS, Ha TH, Chang JS, Park YS, Huh I, Kim J, et al. Seasonality and its distinct clinical correlates in bipolar II disorder. Psychiatry Res 2015;225:540-544.