SPATIAL REGRESSION ANALYSIS OF SOCIAL-HEALTH DETERMINANTS OF COVID-19 IN INDONESIA

Kristiana Yunitaningtyas[1], Betty Roosihermiatie[2] and Suharmiati Suharmiati[3]

[1]Center for Health Financing and Decentralization Policy, Health Policy Agency, Ministry of Health, Jakarta, Indonesia; [2]Research Center for Public Health and Nutrition, [3]Research Center for Pharmaceutical Ingredients and Traditional Medicine, Research Organization for Health, National Research and Innovation Agency Indonesia, Bogor District, Indonesia

Abstract. The first coronavirus disease 2019 (COVID-19) was discovered in Wuhan, China in the end of 2019 that rapidly widespread to the world. In March 2020, World Health Organization (WHO) declared the COVID-19 pandemic. Indonesia reported the first COVID-19 case in early March of 2020. The delta variant of COVID-19 in 2021 caused a sharp increase of COVID-19 in Indonesia reaching 4,262,720 cases and it was the highest in Southeast Asia. The government then distributed the vaccines across the country and intensified vaccination of first and second doses to prevent an increase in COVID-19 cases. Besides, Indonesia has a burden of communicable and non-communicable diseases that can cause a decrease in immunity that risks for COVID-19. This study aimed to determine social and health determinants that influence the numbers of COVID-19 cases in Indonesia in 2021. The dependent variable was COVID-19 cases and independent variables were 1) population density, 2) expenditure per capita, 3) proportion of people with first dose vaccination, 4) proportion of people with second dose vaccination, 5) numbers of vaccine distribution, 6) numbers of tuberculosis cases, and 7) percentage of population having health problems that interrupted daily activities. Data of the study variables in 34 provinces of Indonesia were secondary data retrieved from Ministry of Health and Central Bureau of Statistics of Indonesia. The health and social variables were analyzed with spatial regression to identify their influence on COVID-19 cases. The study showed health determinants significantly affect COVID-19 cases were the proportion of people with second dose vaccination and percentage

of the population having health problems that interrupted daily activities. The result suggests that administering booster vaccination was needed as a way to prevent wider infections of COVID-19. In addition, patients with health problems must be prioritized in obtaining health services during the pandemic of COVID-19 because they have greater risks to be infected.

Keywords: COVID-19, determinants, spatial regression, social and health

Correspondence: Kristiana Yunitaningtyas, Center for Health Financing and Decentralization Policy, Health Policy Agency, Ministry of Health, Jl. Percetakan Negara No. 29, Johar Baru, Kecamatan Johar Baru, Jakarta 10560, Indonesia
Tel: +62 82236886512 E-mail: kristianatyas@gmail.com

INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 or SARS-CoV-2 is the cause of infectious disease known as coronavirus disease 2019 (COVID-19). This infectious disease was first reported by WHO China Country Office in December 2019 based on pneumonia cases in Wuhan City, Hubei Province, China (WHO, 2020). In a fairly short time, WHO then designated the case as Public Health Emergency of International Concern (PHEIC) and declared COVID-19 as a pandemic (WHO, 2020). The status of COVID-19 as a pandemic was in line with the increasing number of cases that occurred in a short time and its rapid spread to various countries in the world, including Indonesia. The first case in Indonesia was reported in March 2020 and as of October 6, 2022 the Ministry of Health has reported 6.4 million of confirmed cases of COVID-19 including 17,047 active cases (Ministry of Health, 2022a).

The number of confirmed cases of COVID-19 and the number of deaths in Indonesia escalated in 2021 due to the new variant of the coronavirus delta. The spread of the delta variant of COVID-19 was faster

than the previous variant, thus reaching almost all provinces in Indonesia. There were 4,262,720 confirmed cases of COVID-19 in 2021, which made Indonesia the country with the highest COVID-19 cases in the Southeast Asia Region (Voice of Indonesia, 2021).

In addition to the transmission of COVID-19, Indonesia itself has a high prevalence of communicable and non-communicable diseases. People having diseases that interrupted their daily activities, especially those with problems of respiratory system have a greater risk factor for COVID-19. A previous study demonstrated that the prevalence of comorbid tuberculosis amongst COVID-19 patients was 1.6% which varied in different regions (Wang *et al*, 2021). Another finding showed that tuberculosis and COVID-19 are dangerous duet and need immediate attention; patients with tuberculosis should be prioritized for COVID-19 prevention as well as vaccination (TB/COVID-19 Global Study Group, 2022).

One of the regulations issued by the government in tackling the transmission of COVID-19 in the community is to maintain a distance between individuals which is indicated on Government Regulation Republic of Indonesia Number 21 of 2020 (Government of Indonesia, 2021). However, the condition of high population density in some areas causes difficulties in implementing the regulation. According to the Central Bureau of Statistics, there is an increase in population density in Indonesia from 141 people/km^2 in 2020 to 142 people/km^2 in 2021 (Central Bureau of Statistics, 2021). Another effort in the health sector carried out by the government was distributing the first and second doses of vaccine throughout the country to prevent the inflation of COVID-19 cases. According to COVID-19 Handling Task Force (2022), approximately 165.2 million first doses and 113.8 million second doses have been administered in 2021.

The transmission of COVID-19 also has an impact on socio-economic aspects. The COVID-19 outbreak has had a significant impact on the economy, especially for workers who have been laid off from their jobs or given temporary leave (Alhassan and Kilishi, 2019). This condition has

an impact on the individual ability to meet their daily needs. Adjusted expenditure per capita in 2021 slightly increased to IDR 11,156,000.00 per person annually when compared with IDR 11,013,000.00 in 2020 (Central Bureau of Statistics, 2021).

This study aimed to look for the social and health perspectives that potentially increased the confirmed cases of COVID-19 in Indonesia during the year 2021.

MATERIALS AND METHODS

The dependent variable in this study was the number of positive confirmed cases of COVID-19 during 2021, at which time Indonesia was the country with the highest confirmed cases of COVID-19 in Southeast Asia. The independent variables used as determinants are the population density, expenditure per capita, proportion of people with first dose vaccination, proportion of people with second dose vaccination, numbers of vaccine distribution, numbers of tuberculosis cases, and percentage of population having health problems that interrupted their daily activities. Each variable in this study is described in detail as follows:

1. Number of confirmed cases of COVID-19

A confirmed case of COVID-19 is a person who has tested positive for the COVID-19 virus as evidenced by reverse transcription-polymerase chain reaction (RT-PCR) laboratory examination. This term was introduced by Ministry of Health (2021). Confirmed cases include 2 types, namely confirmed cases with symptoms (symptomatic) and confirmed cases without symptoms (asymptomatic) which are calculated cumulatively throughout 2021 (Ministry of Health, 2021).

2. Population density (Crude)

Population density is the number of people per unit area.

In the study by Md Iderus *et al* (2022), areas that are highly and densely populated have higher COVID-19 cases and incidence. Crude population density (CPD) shows the total population for each square kilometer of area. The area is the total land area in an administrative area. Population density is expressed as person/km^2 (Central Bureau of Statistics, 2021b).

3. Expenditure per capita

Costs incurred for the consumption of all household members for a year divided by the number of household members. Expenditure per capita is expressed as Indonesian Rupiah (IDR) (Central Bureau of Statistics, 2021).

4. Proportion of people with first dose vaccination

Vaccination aims to increase herd immunity. Vaccines could have a substantial impact on reducing incidence, hospitalizations, and deaths, especially among vulnerable individuals with comorbidities and risk factors associated with severe COVID-19 (Moghadas *et al*, 2021). Based on the study, vaccinations prevented deaths from COVID-19 in 185 countries and territories, there is estimated a global reduction of 63% in total deaths during the first year of COVID-19 vaccination (Watson *et al*, 2022). According to the Ministry of Health (2022b), COVID-19 vaccination has been carried out since January 2021 with a total target of 208,265,720 people aged >12 years old. The coverage of first dose vaccination in Indonesia during 2021 was 80.6%. There are 8 provinces with first dose coverage which exceeds the national number.

5. Proportion of people with second dose vaccination

The study described that the immune response to one dose of the vaccine is relatively weak and people who get only one dose will have only partial immunity to COVID-19 infection (Livingston, 2021). The 2 doses of vaccine were highly effective in preventing infections that cause symptoms (Livingston, 2021). A single dose of vaccine is around 60-70% effective in preventing symptomatic disease in adults and two doses is

around 90-85% effective (Bayati *et al*, 2022). The coverage of second dose vaccination in Indonesia was 55.8%. Five provinces with the highest second dose vaccination were DKI Jakarta (114.4%), Bali (91.6%), Yogyakarta (90.4%), Riau Islands (78.7%), and East Kalimantan (62.6%).

6. Numbers of vaccine distribution

Numbers of vaccine distribution can show the equality of vaccination between different regions in Indonesia. According to the results of Bayati (2022), the most influential factors on vaccine distribution were related to micro level (individual) factors. Demographic and social characteristics were the most important factors influencing the inequality of the distribution of COVID-19 vaccine. The government has distributed 86,253,981 doses of the COVID-19 vaccine until July 2021 (Annur, 2021). Of this amount, the majority of monitored vaccine distribution was still concentrated in Java Island. The majority or 68.47 million vaccine doses that have been distributed are processed by BioFarma (Jakarta, Indonesia). A total of 13.19 million doses distributed were AstraZeneca vaccines (AstraZeneca, Cambridge, England). The remaining three million doses are the CoronaVac vaccine made by Sinovac (Beijing, PR China). Meanwhile, 1.45 million doses and 126 thousand doses vaccines were made by Moderna (Cambridge, MA, USA) and Sinopharm (Beijing, PR China).

7. Numbers of tuberculosis cases

Tuberculosis (TB) is an infectious disease caused by Mycobacterium tuberculosis. The germs spread from TB survivors through the air. This germ usually attacks the lung organs and can also be outside the lungs (extra pulmonary). Currently during COVID-19 pandemic, tuberculosis is still the highest cause of death after HIV/AIDS, and is one of the 20 main causes of death worldwide (Ministry of Health, 2022c). Indonesia is ranked third globally with the highest TB sufferers in the world after India and China (Ministry of Health, 2022c). An observational case-control study conducted by Chen *et al* (2020) has found that patients with tuberculosis

history, both of active tuberculosis and latent tuberculosis, is an important risk factor for SARS-CoV-2 infection and more susceptible to COVID-19 symptom development and progression were more rapid and severe. Another research with non-systematic review carried out by Visca *et al* (2021) shows patients affected by active pulmonary tuberculosis disease can have worse outcomes of COVID-19 because of the interaction of the two infections as the concept of "cursed duet".

8. Population having health problems that interrupt daily activities

This variable indicates the condition of a person who has a health or psychiatric disorder, either due to a disorder/illness that is often experienced or due to acute illness because of an accident, crime, or other health problems (Central Bureau of Statistics, 2021). This can be an indicator of comorbidity that increases the risk of COVID-19 infection. According to current information and study, people with underlying uncontrolled medical conditions are at increased risk of COVID-19 infection and become severely ill (Sanyaolu *et al*, 2020). The health problems include physical and psychological. The variable is expressed as a percentage (%).

The data in this study is secondary data consisting of 34 provinces in Indonesia and taken from various sources. Numbers of confirmed cases of COVID-19 in 2021, proportion of people with first and second doses, and numbers of tuberculosis cases were obtained through reports from the Ministry of Health (Ministry of Health, 2022b). Data of vaccine distribution were acquired from Databoks website which was reported by Annur (2021). Data of population density, per capita expenditure, and percentage of population having health problems were obtained from the Profile of Health Statistics (Central Bureau of Statistics, 2021a).

Spatial regression analysis

The method used to analyze the data was spatial regression analysis

due to the alleged differences in the conditions of COVID-19 transmission in 34 provinces throughout Indonesia. There were provinces that had high confirmed cases of COVID-19 and conversely there were provinces with low confirmed cases of COVID-19. There are 3 types of spatial regression models, namely the Spatial Error Model (SEM), the Spatial Autoregressive Model (SAR), and the Spatial Autoregressive Moving Average (SARMA). The SEM model is a model with a spatial effect on error while the SAR model is a model that occurs due to the spatial influence on the dependent variable lag and the SARMA model is a combination of SAR and SEM models (Yasir *et al*, 2016).

Before the data were analyzed using spatial regression, descriptive analysis was carried out. Descriptive analysis was conducted to see the characteristics of each variable, both independent and dependent variables, in the form of minimum, maximum, median, and mean values. Then, Moran's I test (Moran, 1950) under randomization was conducted to see the autocorrelation between regions.

The next step, spatial regression was carried out. Spatial regression analysis was starting with the Lagrange Multiplier test (Breusch and Pagan, 1980) to determine the best model. From the best spatial regression model, an equation that connects the independent variable with the dependent variable would be obtained. Through this equation, the Akaike Information Criterion (AIC) of the spatial regression would also be acquired to be then compared with the AIC of the classical linear regression. This comparison produced the best method between linear regression and spatial regression to see the relationship between the independent variables and the dependent variable. The entire analysis was processed by RStudio software version 1.3. RStudio is an open source integrated development environment (IDE) for R software. R is developed at Bell Laboratories and can be downloaded on https://cran.r-project.org/mirrors.html and for the RStudio, it is developed by Posit, a Public Benefit Corporation which is available on https://posit.co/download/rstudio-desktop/.

RESULTS

A summary of the variables in this study is shown in Table 1. The dependent variable in this study, namely COVID-19 confirmed cases in 2021, had an overall national average of 125,106 people. The average population density in 2021 was 744.26 people/km^2; the average expenditure per capita in 2021 was IDR 10,760,000.00/person/year; the proportion of people with first dose vaccination in 2021 was 77.51%; the proportion of people with second dose vaccination in 2021 was 51.51%; the average distribution of vaccine in 2021 was 2,301,338; the average numbers of tuberculosis cases in 2021 was 11,688; and the average of percentage of people with health problems that interrupt daily activities in 2021 was 24.96%.

Table 1
Descriptive statistics of variables collected from 34 study provinces

Variable	Minimum	Maximum	Average
COVID-19 confirmed cases 2021	11,833	863,482	125,106
Population density (person/km^2)	9	15,978	744.26
Expenditure per capita (million IDR)	6.955	18.520	10.759
Percentage of people with first dose vaccination	29.30	114.00	77.51
Percentage of people with second dose vaccination	21.20	114.40	51.51
Numbers of vaccine distribution (doses)	160,240	12,443,050	2,301,338
Numbers of tuberculosis cases	995	91,368	11,688
Percentage of people with health problems that interrupt daily activities	12.74	42.15	24.96

COVID-19: Coronavirus disease 2019; IDR: Indonesian Rupiah; km^2: square kilometer

The cumulative number of confirmed positive cases of COVID-19 in Indonesia in 2021 for each province is shown in Table 2. The province with the most confirmed cases of COVID-19 in 2021 is the Capital Region of Jakarta with 863,482 people while the province with the lowest confirmed cases of COVID-19 was Gorontalo with 11,833 people as depicted in Table 2. The confirmed cases of COVID-19 distribution in all provinces in Indonesia is shown in Fig 1. The darker red color indicates the increasing number of confirmed positive cases of COVID-19, on the contrary, the faded color indicates the lower number of cases. The map shows the obvious disparity of confirmed case distribution in various provinces in Indonesia. The highest number of confirmed cases is concentrated around provinces which are marked in dark red and the least occurred in the provinces in the western part of Indonesia which are colored in faded red.

Table 2
COVID-19 confirmed cases of 34 provinces in Indonesia 2021

	Province	No. of confirmed cases
1.	Aceh	38,405
2.	Bali	114,108
3.	Bangka-Belitung	52,210
4.	Banten	132,624
5.	Bengkulu	23,102
6.	Gorontalo	11,833
7.	Papua Barat	34,307
8.	DKI Jakarta	863,482
9.	Jambi	29,764
10.	Jawa Barat	707,345
11.	Jawa Tengah	486,068
12.	Jawa Timur	399,147

Table 2 (cont)

	Province	No. of confirmed cases
13.	Kalimantan Barat	41,448
14.	Kalimantan Selatan	69,889
15.	Kalimantan Tengah	45,601
16.	Kalimantan Timur	158,183
17.	Kalimantan Utara	35,868
18.	Kepulauan Riau	53,875
19.	Lampung	49,659
20.	Maluku Utara	12,097
21.	Maluku	14,585
22.	Nusa Tenggara Barat	27,768
23.	Nusa Tenggara Timur	63,937
24.	Papua	23,322
25.	Riau	128,575
26.	Sulawesi Barat	12,350
27.	Sulawesi Selatan	109,877
28.	Sulawesi Tengah	47,120
29.	Sulawesi Tenggara	20,152
30.	Sulawesi Utara	34,684
31.	Sumatera Barat	89,831
32.	Sumatera Selatan	59,918
33.	Sumatera Utara	105,987
34.	DI Yogyakarta	156,477

Source: Ministry of Health (2022b)

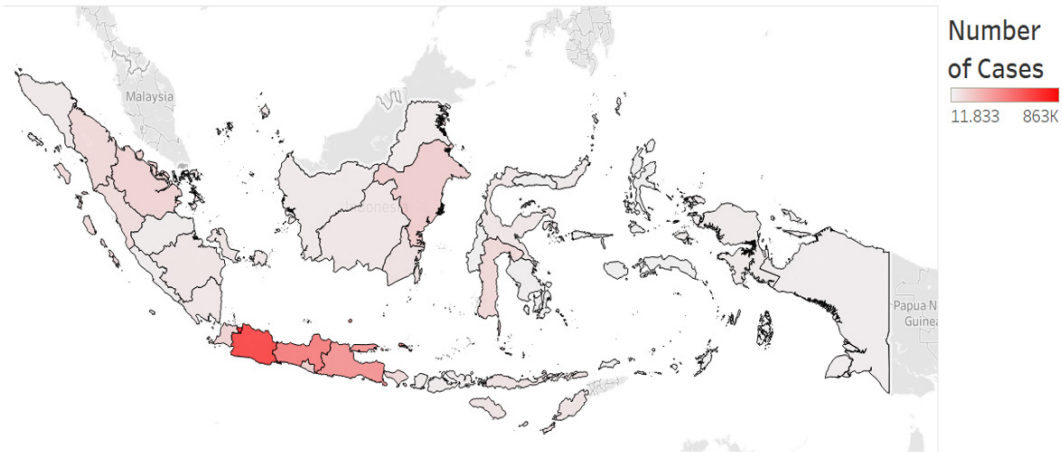

Fig 1 - Heatmap of COVID-19 confirmed cases in Indonesia 2021
COVID-19: Coronavirus disease 2019

The first step in statistical inference analysis is performing Moran's test. Moran's test at the beginning of the spatial regression analysis is intended to see the existence of spatial autocorrelation between regions (Chen, 2013). Based on the results, the statistical value for Moran's index of autocorrelation is 0.18997 and p-value of <0.001 so that there is sufficient evidence to reject the null hypothesis. From this test, it is concluded that a spatial autocorrelation of confirmed cases of COVID-19 in various provinces in Indonesia in 2021 exists.

Furthermore, in this study, classical linear regression analysis was carried out and then compared to the spatial regression analysis model. Classical linear regression does not pay attention to differences in conditions in each region. From this classical linear regression, expenditure per capita, proportion of people with second dose vaccine, and proportion of population having health problems that affect daily activities (p=0.01) significantly affect the cumulative confirmed cases of COVID-19 in 2021.

The independent variables in this study simultaneously affected the dependent variable, namely the confirmed COVID-19 cases in 2021. This is proven by the results of the F-test in regression analysis (p=0.09).

After conducting the classical linear regression, diagnostic testing was carried out to see whether the regression model meets all the assumptions required in the linear regression analysis. Four diagnostic tests were applied on the classical linear regression model, namely heterogeneity, dependency, normality, and autocorrelation. From the test results of the tests, it can be said that the model met all the diagnostics. The error of this model is homogenous with p-value of 0.149 and the distribution of the error is normal with p<0.001 and has no autocorrelation with p<0.001. The AIC value was calculated to assess the goodness of fit of the classical regression model. The AIC value of the classical regression model is 927.71.

Lagrange Multiplier test was performed to identify the spatial dependency model (Breusch and Pagan, 1980). It was carried out to see if there was a spatial effect on the data and to determine the spatial regression model. The Lagrange Multiplier for error dependence (LMerr) and robust Lagrange Multiplier for error dependence (RLMerr) are SEM models while simple Lagrange Multiplier test for a missing spatially lagged dependent variable (LMlag) and robust Lagrange Multiplier test for a missing spatially lagged dependent variable (RLMlag) are SAR models. The results of the Lagrange Multiplier spatial effect test are as follow: LMerr has p-value of 0.051; LMlag has p-value of 0.002; RLMerr has p-value of 0.191; RLMlag has p-value of 0.007 and SARMA has p-value of 0.004. The result indicates that SAR is the most appropriate model to use because it is significant and has the smallest p-value compared to other models.

The next step of the study was applying SAR model to the data to obtain the spatial regression model. The SAR spatial regression model is shown in Table 3.

Table 3
Model of SAR spatial regression

Coefficient	SAR spatial regression	
	Estimate	*p*-value*
Intercept	$3.946x10^{5}$	0.074
Population density	-2.899	0.829
Expenditure per capita	$-4.579x10^{1}$	0.064
Proportion of people with first dose vaccination	$-7.053x10^{3}$	0.064
Proportion of people with second dose vaccination	$-9.516x10^{3}$	0.007
Numbers of vaccine distribution	$-1.2440x10^{-2}$	0.368
Numbers of tuberculosis cases	$-1.594x10^{-1}$	0.315
Percentage of people with health problems that interrupt daily activities	$1.529x10^{4}$	<0.001

*Statistically significant when $p<0.05$

Based on the spatial regression model, proportion of people with second dose vaccination (p=0.007) and percentage of population having health problems that interrupt daily activities (p<0.001) are significant factors affecting the cases of COVID-19. This model produces Rho (ρ) value of 0.481 and p-value of 0.001 with Wald statistic of 15.526 and Wald p-value of <0.001. AIC value of the spatial regression model with SAR effect is 918.61.

DISCUSSION

The data analysis corroborates two models, namely the classical linear regression model and the spatial regression model with the SAR. To obtain the best model, the goodness of fit of the two models are compared using the AIC value. Spatial regression model with SAR effect had AIC

values of 918.61 while classical regression model produced AIC value of 927.71. Thus, the model generated from the spatial regression with the SAR effect is the best model and it is more appropriate to use in describing the data.

Spatial regression analysis with the SAR is shown as the better model. In addition to the lower AIC value, it is also able to accommodate the spatial autocorrelation between regions because based on the Moran's I test result, dependent variable has spatial autocorrelation. According to the previous study, SAR model is appropriately implemented when spatial dependence is suspected in the values of the dependent variable because this condition can give rise to auto-regressive problem (Fang *et al*, 2015). On the contrary, classical linear regression does not fit to describe the data with spatial autocorrelation.

Based on the results presented, the most influential determinants in the cumulative of confirmed cases of COVID-19 were the proportion of people with second dose vaccination and the percentage of the population having health problems that interrupt daily activities. It can be concluded that in every increase of one percent in population getting a second dose vaccine causes less confirmed cases of COVID-19. The more second dose vaccines are administered, the less infections among people of COVID-19 and the herd immunity can be created. This is in line with the finding reported that in 90% of vaccine recipients, antibody was produced after the first dose and it was much higher after the second dose administration (Ghasimiyeh *et al*, 2021) and the 2 doses of vaccines were highly effective in preventing infections that cause symptoms (Livingston, 2021).

Another independent variable that significantly affected the confirmed cases of COVID-19 in Indonesia during pandemic year 2021 was the percentage of people with health problems that interrupt their daily activities. From the model, the more people with health problems, additional infections of COVID-19 observed. The diseases can cause

a decrease in immunity and increase the risk for COVID-19 and become more severely ill than those without health problems. Based on the outcome of systematic review and meta-analysis by Honardoost *et al* (2021), comorbidities affect the severity of COVID-19. The worse outcome of COVID-19 is correlated with the existence of comorbidities.

In summary, spatial regression with SAR effect can describe the relationship between variable dependent, which is confirmed cases of COVID-19 in Indonesia during 2021, and the independent variables. The proportion of people with second dose vaccination and the percentage of population having health problems that interrupt daily activities are estimated to result in an increase of COVID-19 confirmed cases in Indonesia in 2021. Based on the analysis, it is important to create such regulations that promote booster vaccination especially for those who already administered with first dose because only one dose of vaccine is not enough to prevent the infections of COVID-19. On the other hand, more attention needed for patients with latent and active health problems. They must be prioritized in obtaining health services, especially people with serious illnesses. However, patients with comorbidities also should take all necessary precautions to avoid getting infected as they usually have the worst diagnosis.

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CONFLICT OF INTEREST DISCLOSURE

The authors declare that they have no conflict of interest.

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