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ESTIMATING THE NUMBER OF ICU PATIENTS OF COVID-19 BY USING A SIMPLE MATHEMATICAL MODEL

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Abstract. Predicting the number of ICU patients holds significant importance, serving as a critical aspect in efficiently allocating resources, ensuring high-quality care for critically ill individuals, and implementing effective public health strategies to mitigate the impact of diseases. This research focuses on estimating ICU patient numbers through the development of a simple mathematical model. Utilizing data on confirmed COVID-19 cases and deaths, this model becomes a valuable tool for predicting and managing ICU resource requirements during the ongoing pandemic. By incorporating historical data on infected individuals and fatalities from previous weeks, we establish a straightforward equation. We found the substantial impact of the delay in infected individuals, particularly those occurring more than five weeks earlier, on the accuracy of ICU predictions. Proactively preparing for potential surges in severe cases becomes feasible by forecasting the demand for intensive care beds, ultimately improving patient outcomes and preventing excessive strain on medical facilities.

1. Introduction

Since the emergence of COVID-19 in late 2019, the virus has spawned several variants, including Delta and Omicron. Differences in case fatality rates were observed between the Delta and Omicron variants of COVID-19. Delta, emerging earlier, exhibited higher severity and fatality rates compared to the original strains. In contrast, initial observations indicate that the Omicron variant, despite its high transmissibility, may lead to milder cases and lower fatality rates [1, 2].

A higher fatality rate suggests a greater proportion of critically ill patients, emphasizing the need for accurate predictions to ensure adequate an intensive care unit (ICU) capacity and resource allocation. In response to this pressing need, mathematical models have been developed in the previous studies [3, 4, 5],

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although their effectiveness relies heavily on numerous parameters. In the present study, we aim to estimate the number of ICU patients by developing a simple mathematical model. This model provides a valuable tool for predicting and managing ICU resource requirements by using the data on confirmed COVID-19 cases and deaths against the pandemic. By anticipating the demand for intensive care beds, healthcare systems can better prepare for potential surges in severe cases, ultimately improving patient outcomes and preventing overwhelming strain on medical facilities.

2. Methods

2.1. Data description

We used the weekly epidemiological data of the confirmed cases, deaths, and new patients of ICU admission for COVID-19 in the Republic of Korea from February 15, 2021 to March 27, 2023 [6]. Since the vaccination was initiated on February 26, 2021, we started the from February 15, 2021, which includes the first date of vaccination in Korea. As of March 20, 2023, the mandatory mask-wearing requirement in public transportation and large facilities transitioned to a recommendation, and there has been a noticeable decline in the spread of infections. Figure 1 shows the transmission dynamics of the number of confirmed cases (Figure 1A), deaths (Figure 1B), and new patients of ICU admission (Figure 1C).

2.2. Simple mathematical model

The fatality rate is defined as the number of deaths relative to the number of confirmed cases. The number of ICU patients increases with a higher number of COVID-19 cases and a corresponding rise in the number of deaths. Thus, we used the data of the number of COVID-19 cases and the deaths to estimate the number of ICU patients over time. Moreover, it is essential to consider the time delay that it takes for an infected individual to become an ICU patient and to become dead due to the disease to more precisely predict the ICU patient count. We denote the number of cases in time t, $I(t)$ and the number of deaths in time t, $D(t)$. We incorporated the time delay for two data. We estimate the number of ICU patients ($\widehat{ICU}(t)$) during time period T from February 15, 2021 to March 27, 2023. $I(t-n)$ refers to the number of confirmed cases in the preceding n weeks from the time t and $D(t-m)$ refers to the deaths in the preceding m weeks from the time t. Thus, the number of ICU patients ($\widehat{ICU}(t)$) is estimated accounting for the time delay n of the cases, denoted by $I(t-n)$ and the time delay m of the deaths, denoted by $D(t-m)$. We construct a simple mathematical model from the regression analysis as follows.

$$\widehat{ICU}(t) = C_1 + C_2 I(t-n) + C_3 \frac{D(t-m)}{I(t-n) + C_4}, \quad t \in T$$

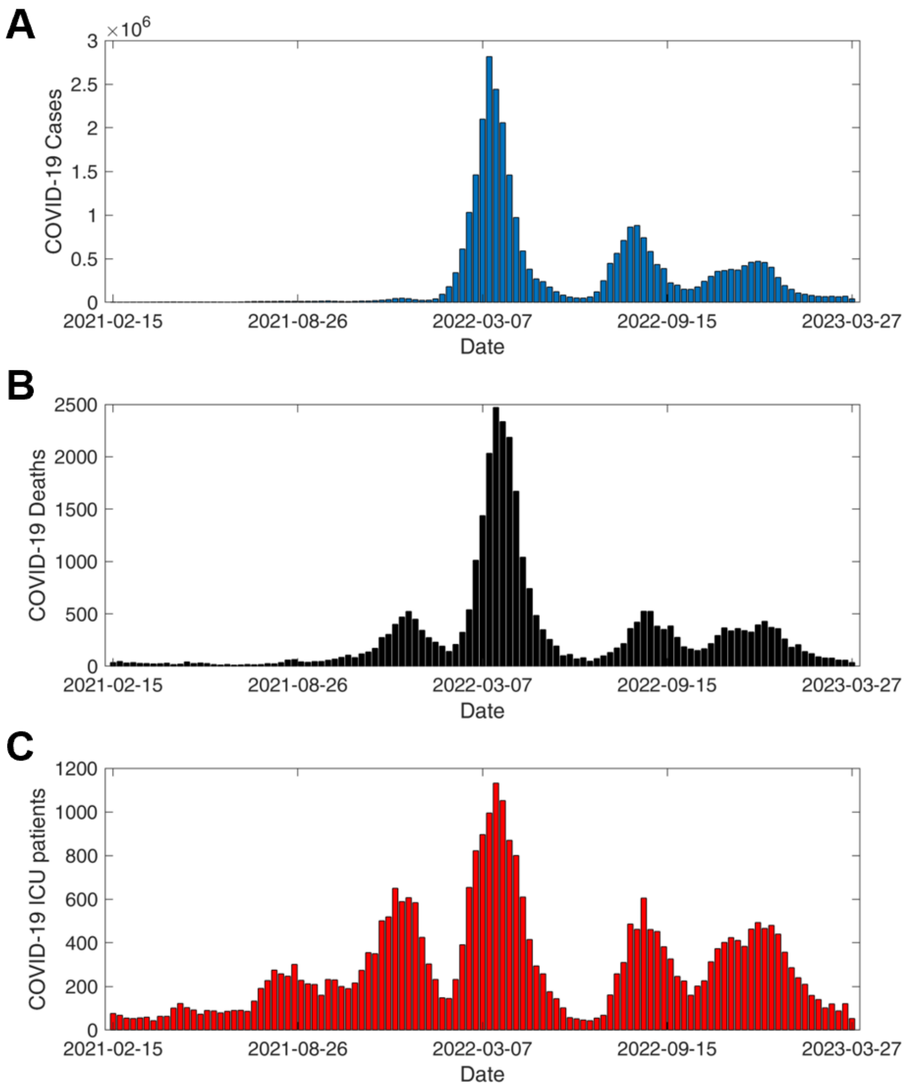

FIGURE 1. COVID-19 data over time in Korea.

where C_1, C_2, C_3, and C_4 are the constant parameters to be estimated. C_1 is the y-intercept and C_2 refers to the change rate of confirmed cases in the preceding n weeks. C_3 refers to the change rate of the case-fatality rate under the augmented cases with the time delays. C_4 indicates the augmented cases for the confirmed cases in the preceding n weeks.

3. Results

3.1. Parameter estimation for the mathematical model

We fitted the observed data into the model in order to estimate the number of ICU patients. We considered the time delay of the cases and deaths as n=5 and m=1, respectively. It means that we used $I(t-5)$ and $D(t-1)$ and the estimated parameters of the model is described in Table 1. Table 2 shows the estimated values of four parameters and P-value. All parameters are statistically significant and we obtained the R^2 at 0.8384 and RMSE at 94.98.

Parameters	Description	Values	P-value
C_1	y-intercept	98.349	< 0.001
C_2	Change rate of confirmed cases in the preceding n weeks	0.0000546	< 0.01
C_3	Change rate of the case-fatality rate under the augmented cases with the time delays	56,873	< 0.001
C_4	Augmented cases for the confirmed cases in the preceding n weeks	48,496	< 0.001

Table 1. Results of parameter estimation and P-values in regression analysis with a delay of 5 weeks and 1 week for COVID-19 cases and deaths

3.2. Comparison of the performance by time delays of COVID-19 cases and deaths

We varied the time delays from 1 week to 6 weeks on the confirmed cases and deaths to estimate the number of ICU patients. We compared the performance of the proposed model according to the different time delays of using the data of cases and deaths. Table 2 described the comparison of the estimated number of ICU patients by the time delay of the cases and deaths from 1 week to 6 weeks.

We found that the maximum values of R^2 at 0.8384 and minimum values of RMSE at 94.98 were obtained when the time delay of the cases and deaths were selected as $n = 5$ and $m = 1$. Moreover, it is clearly observed that when the delay for deaths is short, around one week, and for cases, the delay is relatively longer, exceeding four weeks, the accuracy in terms of R^2 is observed to be consistently above 0.8. It can be understood that infected individuals may influence the progression of ICU patients over time.

Figure 2 compares the estimated ICU patients by the different time delay of the deaths under the fixed delay for the confirmed cases as 5 weeks. In essence, it can be inferred that the delay in deaths has a more significant impact on the predictive outcome of ICU patients than the delay in cases.

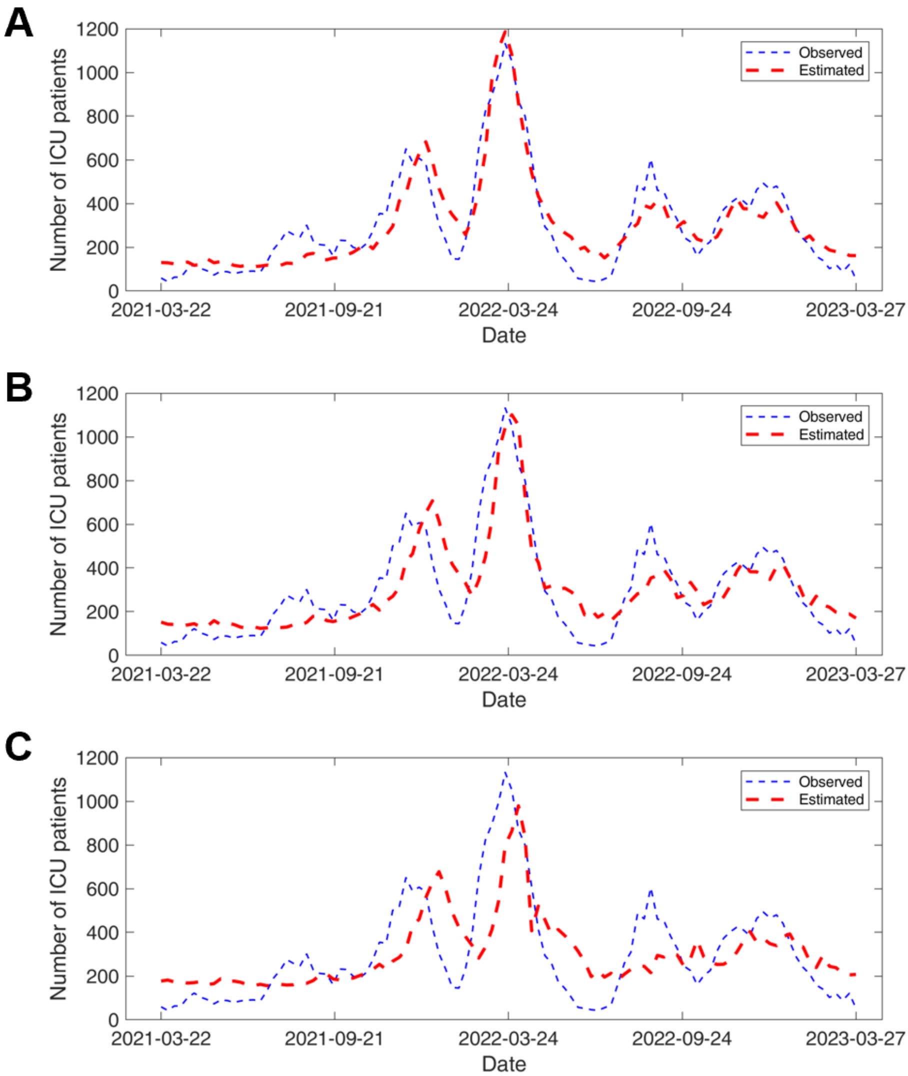

FIGURE 2. Comparison of the estimated number of ICU patients by the time delay of the deaths. Estimation of ICU patients are compared by the delay for the deaths as **A.** 1 week, **B.** 2 weeks, **C.** 3 weeks under the fixed time delay as 5 weeks for the confirmed cases.

Delayed week (Cases)	Delayed week (Deaths)					
	$m = 1$		$m = 2$		$m = 3$	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
$n = 1$	0.8198	101.36	0.7625	115.24	0.7178	125.61
$n = 2$	0.7496	118.35	0.6742	135.00	0.6739	135.70
$n = 3$	0.7980	106.28	0.5460	159.33	0.5326	162.43
$n = 4$	0.8302	97.40	0.6423	141.37	0.3348	192.78
$n = 5$	0.8384	94.98	0.7117	126.86	0.4654	172.75
$n = 6$	0.8295	97.52	0.7418	120.00	0.5586	156.90

TABLE 2. R^2 and RMSE in estimating the number of ICU patients based on the delay in the COVID-19 cases and deaths

4. Discussion

Managing the ICU beds is of substantial significance, playing a crucial role in implementing successful public health strategies to minimize the impact of diseases. In the present study, we newly developed the simple mathematical model by using only previous data of the confirmed cases and deaths to estimate the number of ICU beds. We found that the substantial impact of the delay in infected individuals than those in deaths.

We do not consider the forecasting of the ICU patients depending on the control interventions. There are several previous studies in [7, 8, 9, 10] for the forecasting the ICU patients. Instead of relying on the complex mathematical models, we developed the simple model that requires only the data of cases and deaths over time. Consequently, the ICU patients are well estimated, with the R^2 value of approximately 0.8. It could give a valuable tool for estimating ICU bed capacity during an ongoing pandemic of a novel disease. Predicting the need for ICU beds in advance aids in proactive preparation for potential surges in severe cases, thereby mitigating the risk and reducing the impact of severe cases.

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