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Impact of COVID-19 on Severe Trauma Patients in Korea: A Nationwide Regional Subgroup Analysis

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Original Research

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Abstract

Objectives: This study aimed to examine the regional impact of COVID-19 on severe trauma patients in South Korea.

Methods: This study utilized Community-based Severe Trauma Survey data from the Korea Disease Control and Prevention Agency. The average treatment effect (ATE) of COVID-19 on severe trauma patients by region was determined using doubly robust estimation (DR). Subgroup analysis was conducted for the greater Seoul area, metropolitan cities in rural areas, and rural areas.

Results: Significant differences were observed in the general characteristics of participants before and after the COVID-19 outbreak, particularly in the mechanisms of injury and types of hospitals to which they were transported. DR revealed that the probability of death among severe trauma patients was higher in metropolitan cities in rural areas than in other regions.

Conclusions: The greater impact of COVID-19 on severe trauma patients in metropolitan cities in rural areas is attributed to their higher population density and the inability of emergency medical systems to manage the spread of COVID-19. Therefore, future national policies related to emergency medical care should focus on enhancing the capacity for managing infectious diseases in large-scale metropolitan cities.

Injuries significantly contribute to the disease burden among the population of Korea. According to the Global Burden of Disease study, as of 2019, self-harm, falls, road injuries, and mechanical forces ranked among the top 30 causes contributing to the greatest disease burden across all conditions.[1] Additionally, recent findings from the Korean National Burden of Disease Study indicate that, based on 2020 data, falls, self-harm, and motorized vehicles with 3 or more wheels were among the top 20 leading causes.[2] While the landscape of disease burden in Korea has evolved over time, injuries continue to impose significant burden.

The first COVID-19 case in Korea was detected on January 29, 2020, followed by the World Health Organization's declaration of the COVID-19 pandemic on March 11, 2020.[3] Subsequently, significant changes in health care utilization occurred worldwide, including in Korea, profoundly impacting the health care system. After the outbreak of COVID-19, various countries, including Korea, experienced an increase in the response time of emergency medical systems (EMS), with notable changes in its patterns.[4–9]

After the COVID-19 outbreak, many countries observed a decrease in the number of trauma patients and their health care utilization.[4] Additionally, these patients' characteristics (mechanisms of injury and mortality rates) changed, with significant differences noted.[9] In Korea, a difference in mortality rates was also observed between 2019 and 2020.[7] Specifically, changes occurred in Korea's EMS system after COVID-19 outbreak, including a decrease in patient transfers and an increase in EMS time intervals.[6,8] These changes suggest that the significant impact of COVID-19 on emergency trauma patients, including EMS.

However, previous studies have some limitations in describing the phenomena observed before and after COVID-19 or focusing only on a single institute.[5] While prior research has investigated the impact of COVID-19 on admission and death of severe emergency patients, it is limited to observing associations rather than causal effects.[7] Additionally, as COVID-19 is an infectious disease, its impact can vary according to various sociodemographic factors such as population density, indicating that the effect of COVID-19 on trauma patients may differ by regions.

Furthermore, the field of severe trauma is significantly influenced by the patient's location in terms of outcomes. For example, the transportation and outcomes of trauma patients vary by region.[10] Considering the impact of regional characteristics on severe trauma patients and the varied effects of COVID-19 by regional specifics, the impact of COVID-19 on severe trauma

patients should be explored by region. Hence, this study aimed to understand the influence of COVID-19 on outcomes of severe trauma patients in Korea by region.

Methods

Study Design and Population

To examine the effect of COVID-19 across various regions, this study used Community-based Severe Trauma Survey data from the Korea Disease Control and Prevention Agency (KDCA). This dataset was constructed by investigating the total population of severely injured individuals and multiple casualties transported by 119 paramedics from 2016 to 2021.

To compile this dataset, data from the National Fire Agency and 119 paramedics were linked with medical records, and all individuals were anonymized. Additionally, a comprehensive survey was conducted to include data on further treatments for patients transferred from the first hospital to another. This dataset encompasses information on patients' socioeconomic characteristics, incident-related details, injury-related information, initial medical consultation details, and information about secondary transfer hospitals.

Community-based Severe Trauma Survey data were constructed from emergency medical service records created by 119 paramedics, focusing on cases where the Revised Trauma Score was abnormal or the emergency team had completed a detailed emergency treatment form. For this study, severe trauma patients were identified as the study population, excluding those who were part of a single disaster situation involving multiple casualties and those whose conditions were not caused by trauma. Additionally, to distinguish severity among trauma patients, individuals with an Injury Severity Score of 16 or above were selected as the study population (Figure 1).

Ethics and data availability

The Institutional Review Board (IRB) of the Korea University (IRB No. KUIRB-2024-0216-01) approved this study and waived the need for informed consent. The data used in this study can be obtained by submitting a request to the KDCA's National Injury Information Portal, which is available from the authors upon reasonable request and with permission of KDCA.

Data analysis

To assess the regional impact of COVID-19 on severe trauma patients, this study measured the average treatment effect (ATE) using doubly robust estimation (DR). Beyond discovering associations, deriving causality from observed data is challenging.[11] To ascertain causality, covariates other than the variable of interest must be identical. DR combines outcome regression (OR) and inverse probability weighting (IPW), creating weights based on propensity scores (PS) to adjust each covariate, making them equivalent.[12] By combining these 2 methods DR calculates consistent estimator even when either 1 of 2 models misspecifie.[13] This dual approach makes DR a more robust model for causal inference compared to conventional PS methods. The standardized difference is then used to verify whether individual covariates have been appropriately adjusted in IPW; a value of 0.1 or less indicates that the baseline covariates have been properly adjusted through weight application.[14]

DR estimation offers a distinct advantage over traditional methodologies in measuring causality more robustly. In traditional regression analysis, the relationship identified between variables is typically an association, making it challenging to clearly define the direction of influence—whether the independent variable drives changes in the dependent variable or vice versa.

To address this, statistical methodologies have emerged to strengthen the inference of causality over mere correlation within available data sources. PS methods provide a means to analyze the relationship between variables with enhanced causal inference compared to traditional regression models. By balancing the distribution of confounding variables between experimental and control groups, PS enables the causal effects of independent variables to be assessed more accurately. Because DR estimation uses IPW based on PS and OR to strengthen the robustness of estimation, DR estimation offers more precise information than PS methods.

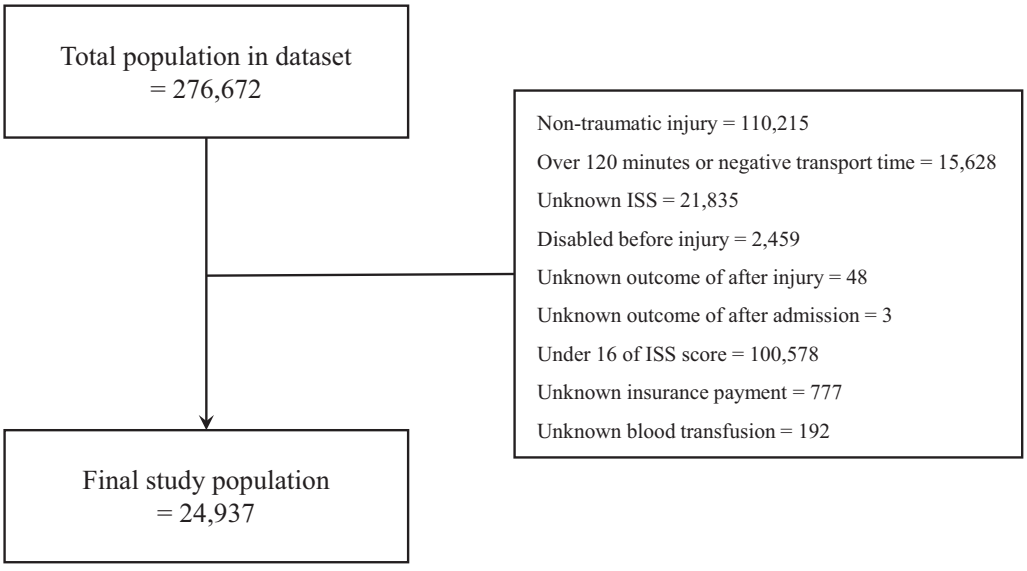

Figure 1. Flow chart of study population selection.

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After adjusting covariates using the mentioned method, potential outcome means for both the experimental and control groups are calculated. Subtracting the potential outcome mean of the control group from that of the experimental group yields the ATE. The calculated ATE allows for the observation of the effect of the variable of interest on a specific outcome, excluding the effects of the given covariates in the model. This is significant in measuring causality, a step beyond association, unlike traditional regression models.

Therefore, the ATE of COVID-19 on mortality was analyzed among severe trauma patients before and after the pandemic across different regions to understand the impact COVID-19 has had on severe trauma patients. To achieve this, the study divided Korea into 3 subgroups: the greater Seoul area, which includes the surrounding region of Seoul; metropolitan cities in rural areas; and rural areas. This classification is based on the concentration of medical resources in Seoul and the greater Seoul area, as well as the deployment of emergency medical resources around metropolitan cities in regions outside of the greater Seoul area.[15,16] ATE was calculated using the DR method.

In South Korea, economic and social security growth has historically been concentrated around Seoul and metropolitan cities in the region. Rapid urbanization has led to significant migration from rural areas to these metropolitan centers, resulting in the concentration of much of the country's economic and social infrastructure in urban areas.[17]

South Korea's health care system, predominantly driven by private providers, exhibits a similar pattern, with medical resources disproportionately allocated to areas with higher demand. Emergency medical resources are no exception; the greater Seoul area and metropolitan cities in rural areas benefit from abundant emergency medical resources and high accessibility, whereas rural areas face significant disparities in resource availability and access.[18]

Considering the availability of data from 2016 to 2021, 2 models were set for ATE estimation: Model 1 comprised data from 2016-2019 as pre-pandemic data, while Model 2 used data from 2018-2019 separately for comparison with data from 2020-2021 as during-pandemic data.

Results

Characteristics of Study Population

The transportation of severe trauma patients changed before and after COVID-19, with a particularly notable increase in transfers to regional trauma centers, from 31.38% to 52.70% ($P < 0.001$). Regarding the mechanism of injury, there was a decrease in traffic accidents and an increase in falls after the COVID-19 outbreak ($P < 0.001$). In terms of intent, the proportion of self-harm increased during-pandemic compared to that pre-pandemic ($P < 0.001$), and the portion of medical expenses paid by national health insurance increased, while those covered by car insurance decreased ($P < 0.001$). Moreover, the proportion of severe trauma patient deaths increased during-pandemic compared to that pre-pandemic ($P < 0.001$). The transportation time increased during-pandemic compared to that pre-pandemic ($P < 0.001$).

Comparing 2018-19 and 2020-21, the differences in the characteristics of the study population observed between pre-pandemic and during-pandemic can be re-confirmed. However, there are differences in some areas, particularly in terms of age and proportion of severe trauma patients who died. Among severe trauma patients, the proportion of patients who died was higher in 2020-21 than in 2018-19, but this difference was not statistically significant ($P = 0.36$), and the age difference was also not statistically significant ($P = 0.21$).

ATE Estimation Using DR

Before measuring the ATE, a balance check of the covariates must be conducted. The balance check results for both models showed that the absolute value of the standardized difference was less than 0.1, indicating that the adjustment of covariates was appropriately conducted (Supplementary Tables 1 and 2).

Both Model 1 and Model 2, designed for DR estimation, had identical distributions of covariates. In other words, the distributions of covariates were balanced across the pre- and post-COVID-19 groups. This balance ensures the necessary conditions to estimate the ATE of COVID-19 on patient outcomes, which includes causal impact.

The results of examining the ATE for the difference in deaths of severe trauma patients before and after COVID-19 are as follows (Tables 3 and 4). In models comparing pre-pandemic and during-pandemic periods, as well as those comparing 2018-19 and 2020-21, the probability of death among severe trauma patients was higher after the COVID-19 outbreak than before in metropolitan cities in rural areas. The value of the ATE for metropolitan cities in each model was -0.046 and -0.061, respectively. In contrast, for the greater Seoul area and rural areas, statistically significant ATE values could not be confirmed in either model, except for rural areas in Model 1, which shows a positive value of ATE (Figure 2).

Discussion

This study utilized population data of severe trauma patients transported by 119 paramedics in Korea from 2016-2021 to examine the differences in patient characteristics and outcomes before and after COVID-19. The results showed various differences in patient characteristics before and after the onset of COVID-19, including an increase in transportation time for severe trauma patients and an observed increase in falls as a mechanism of injury compared to before the pandemic. This trend is consistent with previous research conducted in various countries, as the impact of COVID-19 led to increased indoor activities, a decrease in trauma patients, and difficulties in accessing emergency medical services, which are considered to be the cause.[19]

Specifically, the observed changes in the overall characteristics of trauma patients before and after COVID-19 appear to be influenced by the implementation of physical and social distancing, a key component of the pandemic response strategy.[20] In South Korea, strategies such as shutdowns, working from home, and administrative orders to ban gatherings following the COVID-19 outbreak led to a significant reduction in population mobility.[21]

As mobility decreased, road traffic volume declined, and policies that kept people at home for extended periods resulted in a reduction in traffic-related injuries and an increase in fall-related injuries. These shifts in injury mechanisms have been reported in previous studies and align with the findings of prior research.[22,23]

Additionally, this study is significant for utilizing the DR methodology to measure ATE, differing from previous research. This methodology is used to identify causality from observational data, underscoring the importance of quantitatively understanding the impact of COVID-19 on the outcomes of severe trauma patients in Korea. The results from both DR models confirmed that COVID-

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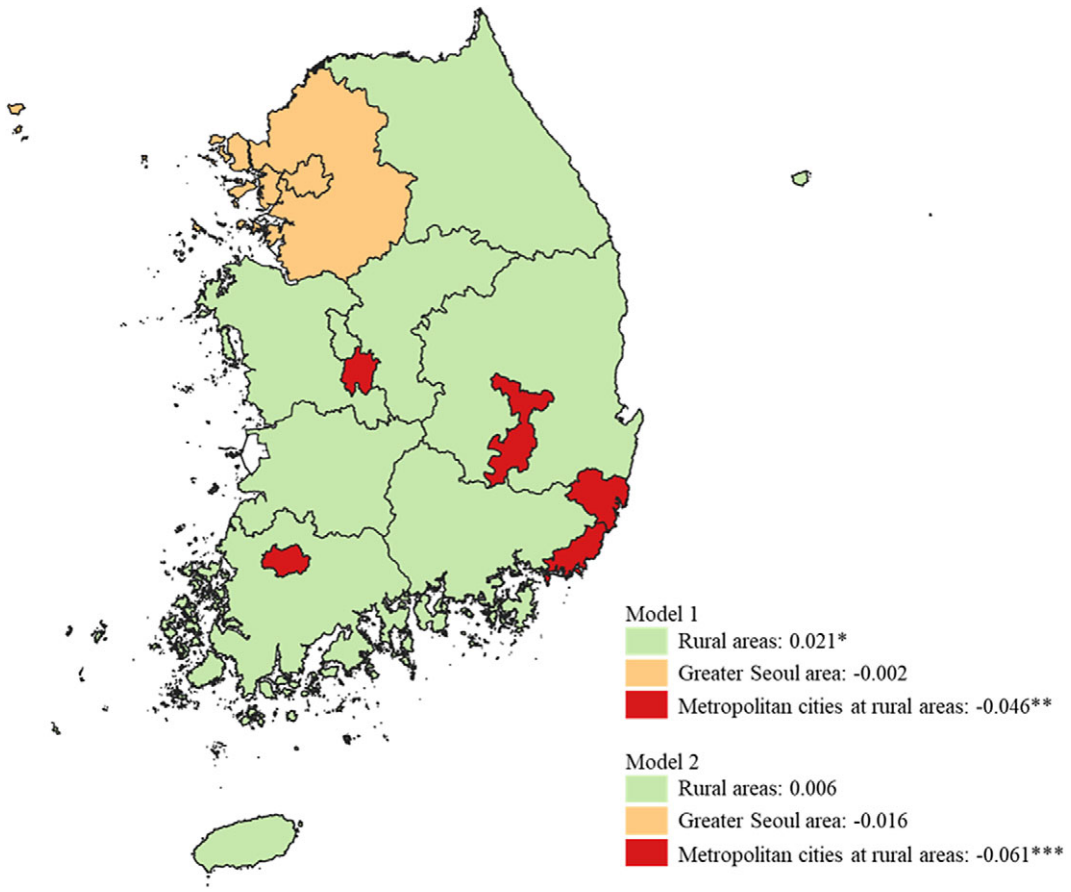

Figure 2. Results of average treatment effect by region.

19 had a negative effect on the outcomes of severe trauma patients in metropolitan cities in rural areas. In other words, it was observed that the probability of death for severe trauma patients in metropolitan cities increased after the outbreak of COVID-19 compared to before.

This phenomenon is believed to stem from the characteristics of infectious diseases like COVID-19. According to previous research, infectious diseases have a higher relevance index compared to other diseases,[24] resulting in a higher proportion of medical services being delivered within the residence or area of occurrence. In other words, the rapid spread of a specific infectious disease can suddenly impact the local health care system.

Previous studies have shown that health outcomes in metropolitan cities within rural areas are poorer compared to other regions over time.[25] This suggests that the overall health status in these areas is lower than in other parts of the country. Furthermore, the lack of EMS infrastructure, particularly facilities such as Regional Emergency Medical Centers (REMCs) and Local Emergency Medical Centers (LEMCs), likely exacerbated the impact of COVID-19 on severe trauma patients in these regions (Table 5).

Metropolitan cities within rural areas have a higher population density than rural areas, increasing the risk of infection. While these cities face greater infection risks, their EMS infrastructure is less developed compared to the greater Seoul area, leaving them more vulnerable to the impact of COVID-19. Due to the nature of infectious diseases, patients are typically treated within the outbreak area, and concerns over infection often hinder the timely treatment of trauma patients. These factors suggest that metropolitan cities in rural areas experienced a greater adverse impact from COVID-19 than rural areas.

Emergency medical institutions in South Korea are broadly categorized into 4 types, as outlined in Tables 1 and 2. Among these, facilities within the REMC category, with a specialized capacity for managing trauma patients, are designated as Regional Trauma Centers. REMCs are larger institutions compared to LEMCs, and both are classified as general hospitals. While LEMCs have no specific requirements regarding the number of beds, REMCs must have at least 300 beds.

In essence, REMCs serve as the central emergency care institutions within their respective regions, focusing on critical emergency patients and overseeing the overall management of emergency medical services within their jurisdiction. Table 5 provides an overview of the regional distribution of different types of emergency medical institutions.

Larger emergency medical institutions with diverse capabilities, such as REMCs, are concentrated in the Seoul metropolitan area. However, the number of LEMCs and Local Emergency Treatment Centers, which handle the practical care and transport of emergency patients, remains relatively low.

Although metropolitan cities within rural areas occupy a smaller geographical area compared to the greater Seoul area or rural areas, they play a critical role as regional hubs for emergency care. Considering their responsibility to accommodate emergency patients from surrounding rural areas, there is a clear need to strengthen the EMS infrastructure in these regions.

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Table 1. Characteristics of study population in model 1

Variables	Pre-pandemic		During-pandemic		*P* value
	Number mean	% Standard deviation	Number mean	% Standard deviation	
Sex					
Male	12488	74.77	6167	74.90	0.82
Female	4215	25.23	2067	25.10	
Transportation					
Regional trauma center	5241	31.38	4339	52.70	<0.001
Regional emergency medical center	4098	24.53	1514	18.39	
Local emergency medical center	6085	36.43	1998	24.27	
Local emergency treatment center	1279	7.66	383	4.65	
Mechanism of injury					
Traffic accident	10202	61.08	4690	56.96	<0.001
Fall	5584	33.43	3049	37.03	
Blunt	504	3.02	292	3.55	
Penetration	219	1.31	121	1.47	
Machine	194	1.16	82	1.00	
Intent					
Unintended injury	15518	92.91	7441	90.37	<0.001
Self-harm	519	3.11	417	5.06	
Violence	220	1.32	118	1.43	
Unknown	446	2.67	258	3.13	
Insurance type					
National health insurance	7413	44.38	4165	50.58	<0.001
Car insurance	7571	45.33	3144	38.18	
Industrial Accident Compensation Insurance	1038	6.21	538	6.53	
Other	681	4.08	387	4.70	
Blood transfusion					
Yes	9499	56.87	4644	56.40	0.48
No	7204	43.13	3590	43.60	
Occurrence of death					
Yes	12401	74.24	6358	77.22	<0.001
No	4302	25.76	1876	22.78	
Age	53.79	19.32	54.69	19.33	<0.001
Transport Time					
Accident site to hospital arrival	32.08	17.86	40.40	20.56	<0.001
Hospital arrival to emergency room	4.52	5.20	4.83	4.91	<0.001

Considering the characteristics of infectious diseases, there is a positive association between population density and the spread of COVID-19.[26,27] As population density increases, the spread of infectious diseases accelerates, impacting the health care system in the area and leading to worsened outcomes for severe trauma patients in metropolitan cities due to COVID-19. However, in rural areas, where the impact of COVID-19 is not as pronounced as in metropolitan cities, the mortality due to COVID-19 is not as significant. Therefore, in planning future national emergency medical plans, efforts to lower mortality rates through the enhancement of treatment and transportation of severe trauma patients during pandemics should focus on larger cities, such as metropolitan cities in rural areas.

This study is valuable for examining the impact of COVID-19 on the outcomes of severe trauma patients transported by 119 paramedics, adjusting covariates as much as possible, which differs from previous studies. However, to strictly ascertain the causal effect, certain conditions are needed: all covariates that may be associated

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Table 2. Characteristics of study population in model 2

Variables	2018-19		2020-21		*P* value
	Number mean	% Standard deviation	Number mean	% Standard deviation	
Sex					
Male	6748	74.08	6167	74.90	0.22
Female	2361	25.92	2067	25.10	
Transportation					
Regional trauma center	3677	40.37	4339	52.70	<0.001
Regional emergency medical center	2041	22.41	1514	18.39	
Local emergency medical center	2878	31.60	1998	24.27	
Local emergency treatment center	513	5.63	383	4.65	
Mechanism of injury					
Traffic accident	5448	59.81	4690	56.96	<0.01
Fall	3121	34.26	3049	37.03	
Blunt	298	3.27	292	3.55	
Penetration	134	1.47	121	1.47	
Machine	108	1.19	82	1.00	
Intent					
Unintended injury	8436	92.61	7441	90.37	<0.001
Self-harm	314	3.45	417	5.06	
Violence	122	1.34	118	1.43	
Unknown	237	2.60	258	3.13	
Insurance type					
National health insurance	4038	44.33	4165	50.58	<0.001
Car insurance	4083	44.82	3144	38.18	
Industrial Accident Compensation Insurance	614	6.74	538	6.53	
Other	374	4.11	387	4.70	
Blood transfusion					
Yes	5291	58.09	4644	56.40	0.03
No	3818	41.91	3590	43.60	
Occurrence of death					
Yes	6980	76.63	6358	77.22	0.36
No	2129	23.37	1876	22.78	
Age	54.32	19.24	54.69	19.33	0.21
Transport Time					
Accident site to hospital arrival	33.26	18.21	40.40	20.56	<0.001
Hospital arrival to emergency room	4.41	5.23	4.83	4.91	<0.001

with treatment assignment and variables associated with the outcome must be included.[28] However, this study still has some challenges in that it could not control for clinical characteristics, such as the specific injuries of each patient.

Additionally, the ATE values of Model 1 and Model 2 differed in this study, suggesting that Model 1, which aggregated data from 2016-2019, did not control covariates as effectively as Model 2, even though the same variables were used. The emergency medical system in Korea has rapidly evolved compared to that in the past.[29] In the case of EMS in Korea, the second basic plan for EMS was established in 2013, with a key task related to severe trauma being the deployment of 17 regional trauma centers and the training of specialized doctors by 2017. Following this, the third basic plan was set for 2018-2022, laying the foundation for the quantitative growth of the second basic plan to be solidified.

While Model 1, which includes dramatic changes in EMS over time, had some values showing positive ATE values in rural areas, this implies that other uncontrolled covariates needed to be

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Table 3. Model 1: effect of COVID-19 on severe trauma patient's outcome by regions between pre-pandemic and during-pandemic

Regions	Potential outcome means		
	Pre-pandemic	During-pandemic	ATE
Greater Seoul area	0.235	0.237	–0.002 (–0.020, 0.016)
Metropolitan cities at rural areas	0.249	0.295	–0.046** (–0.074, –0.017)
Rural areas	0.263	0.242	0.021* (0.004, 0.038)

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 4. Model 2: effect of COVID-19 on severe trauma patient's outcome by regions between 2018-19 and 2020-21

Regions	Potential outcome means		
	2018-19	2020-21	ATE
Greater Seoul area	0.210	0.226	–0.016 (–0.036, 0.003)
Metropolitan cities at rural areas	0.225	0.286	–0.061*** (–0.091, –0.030)
Rural areas	0.240	0.234	0.006 (–0.012, 0.025)

* $P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

considered for a better examination, which is a limitation of Model 1. However, when analyzing data with the least temporal difference, specifically between 2018-19 and 2020-21, the fact that ATE values appeared negatively in the greater Seoul area suggests a negative impact of COVID-19 on severe trauma patients, even though some values are not statistically significant. Moreover, the ATE value for rural areas turned out to be not significant.

EMS in South Korea has undergone significant advancements across multiple dimensions. These include observable improvements in data, such as increased EMS resources for trauma patients and better patient outcomes, as well as less easily quantifiable changes, such as enhanced patient management systems in emergency medical institutions and the acquisition of critical physical and human resources, such as advanced medical equipment.

A notable example is the Emergency Medical Service Act, which was enacted in 1994 and implemented in 1995. By 2021, the act had been amended 74 times, with nearly half of those amendments (n = 34) occurring between 2016-2021. This reflects a sustained effort since the mid-2010s to establish comprehensive EMS infrastructure and to define and enhance the roles and quality standards of these systems.

To minimize the impact of changes that are difficult to observe with the available data, an additional analysis was conducted by selecting groups with minimal temporal differences. The results showed that in Model 1, which covered a longer timeframe than Model 2, patient outcomes in rural areas were better during the pandemic period. In contrast, Model 2, which minimized the impact of temporal improvements in the quality of emergency medical services, yielded statistically insignificant ATE values.

This indicates that Model 2, compared to Model 1, more effectively controlled for unobservable variables associated with temporal changes, allowing for a clearer assessment of the direct impact of COVID-19 on patient outcomes.

Nevertheless, this study identified the varying impacts of COVID-19 across different regions and, in particular, found an increase in the probability of mortality in severe trauma patients due to COVID-19 in metropolitan cities in rural areas. This suggests that metropolitan cities, compared to other regions, require enhanced management of severe trauma patients during an infectious disease outbreak, indicating the need to strengthen Korea's EMS in the future.

Currently, Korea's EMS requires both quantitative growth and various qualitative improvements.[30] As this study discusses, including severe trauma and other emergency medical conditions such as cerebrovascular diseases, while transportation to hospitals is adequately conducted, final treatment often fails to be effectively delivered. This existing issue was exacerbated by the outbreak of COVID-19, worsening outcomes for emergency patients[7] as well as extending time for transportation.[8] Examining the current state of Korea's EMS system, the EMS system should be strengthened during pandemics, particularly considering infectious disease management in densely populated metropolitan cities when planning future EMS strategies.

Additionally, this study controlled for the time it took for 119 paramedics to reach the initial emergency medical facility and the type of emergency medical institution, considering the previous study.[6,8,31] This implies that individuals before and after the COVID-19 outbreak had the same distribution of transportation times when

Table 5. Allocation of emergency medical institutions in South Korea by region

Categories		2016	2017	2018	2019	2020	2021
Regional emergency medical center	Greater Seoul area	13	14	14	14	14	14
	Metropolitan cities at rural areas	7	8	8	8	8	8
	Rural areas	11	14	14	16	16	16
Local emergency medical center	Greater Seoul area	57	58	58	62	65	64
	Metropolitan cities at rural areas	20	19	19	19	20	20
	Rural areas	43	42	41	43	43	43
Local emergency treatment center	Greater Seoul area	62	65	61	59	55	58
	Metropolitan cities at rural areas	60	60	53	54	53	53
	Rural areas	139	135	134	126	127	126

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measuring the ATE. Ultimately, this suggests that differences at the hospital stage influenced patient outcomes before and after COVID-19. Along with improving the quality of the EMS system in metropolitan cities in response to infectious diseases, emergency patient management should be strengthened at the hospital level.

Limitations

This study has the following limitations. The data used for analysis in this study does not include clinical information about the patients, such as whether they had underlying diseases or the specific locations of their injuries. However, to minimize this limitation, the study excluded individuals with pre-existing disabilities using the Glasgow Outcome Scale during the implementation of DR and included variables such as blood transfusions to match clinical characteristics. A notable limitation of this study is the lack of clinical data, such as whether trauma patients transported during the COVID-19 period were infected with COVID-19.

Hemorrhage poses a critical challenge for patients with severe trauma. Although the causal impact of COVID-19 on complications and mortality remains unclear, there have been reported cases indicating a negative influence of COVID-19 on hemorrhage-related outcomes.

Patients with both trauma and COVID-19 may have a higher likelihood of mortality due to various complications compared to trauma patients without COVID-19. Therefore, future studies should incorporate clinical data to further elaborate on how COVID-19 and other clinical characteristics influence patient outcomes.[32,33]

Additionally, there is a limitation in controlling for a sufficient number of variables to establish complete causality when measuring ATE using DR in Model 1. This is particularly evident when comparing the ATE values of Model 1 and Model 2. Model 1, which analyzes data over a longer period, cannot fully control for various conditions, such as systemic changes and quality improvements in EMS across years, unlike Model 2, which has less variation due to focusing on a shorter time span. However, to minimize these changes, data analysis was conducted by controlling for various variables, such as the type of hospital transported to and transport time. By measuring ATE in different time periods, the result of Model 2 complements the results of Model 1.

Conclusions

Although EMS has improved over time, the COVID-19 pandemic has highlighted the need for further development and to identify issues within EMS during the pandemic, given that it ended relatively recently. The study results indicate that large cities like Seoul and other metropolitan areas had worse outcomes for severe trauma patients due to COVID-19 compared to other regions. Therefore, EMS should be strengthened in densely populated and large-scale areas to prepare for potential future pandemics.

To improve outcomes for trauma patients during infectious disease outbreaks, there is a need to increase the availability of negative pressure isolation rooms (NPIRs). However, given the concentration of health care resources in the greater Seoul area, medical demand should be assessed in different regions, and NPIR expansion should be planned accordingly. Various policy measures can be employed, from regulatory strategies that strengthen designation criteria for emergency medical institutions equipped with NPIRs to financial incentive policies promoting NPIR expansion.

Considering South Korea's predominantly private health care system, if such policies have limited impact on private providers, it may be necessary to allocate public funding to expand NPIR facilities in public hospitals to address market failures.

Additionally, from a long-term perspective, a regional, function-based plan should be established for bed capacity management. Based on the regional analysis conducted in this study, the area with the highest number of hospital beds per 1000 population is the metropolitan cities located in rural areas. This indicates that, despite having abundant physical resources relative to the population, these resources are not being utilized effectively. To address this, future hospital bed management policies in South Korea should assess the demand for beds with specific functions and redefine the allocation and functionality of hospital beds accordingly.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/dmp.2025.115.

Data availability statement. The datasets generated and/or analyzed during the current study are available in the KDCA National Injury Information Portal. Data are, however, available from the authors upon reasonable request and with permission of KDCA.

Author contribution. All authors (Kim CN, Yoon SJ) contributed to writing and conception of this study. Kim CN collected data and conducted statistical analysis.

Competing interests. The authors declare none.

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