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Indirect Impact of the COVID-19 Pandemic on All-Cause Mortality and Cardiovascular Disease Among People With Diabetes Mellitus From Korea and Hong Kong: An Interrupted Time Series Analysis

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ABSTRACT

Background and Aims: The COVID-19 pandemic disrupted healthcare systems globally, raising concerns about its impact on the continuing care of people with chronic conditions such as diabetes mellitus (DM). However, few studies have quantified such indirect impact among individuals who were not infected by SARS-CoV-2. This study aimed to assess the pandemic's indirect impact on all-cause mortality, cardiovascular disease (CVD) diagnoses, and healthcare utilization among people with DM in Korea and Hong Kong.

Methods: We conducted a retrospective, closed-cohort study of 1,226,685 individuals (926,230 from Korea; 302,455 from Hong Kong) with a documented diagnosis of DM in 2014 but without any existing cardiovascular disease (CVD) or SARS-CoV-2 infection from January 2015 to December 2021. The cohorts were followed from January 2015 to December 2021. Interrupted time series analysis was used to assess monthly changes in all-cause mortality, CVD incidence, and healthcare utilization rates during the pandemic, compared to those in the pre-pandemic period.

Results: After the initial COVID-19 outbreak in February 2020, all-cause mortality did not change significantly in either location. In Hong Kong, CVD incidence significantly declined in 2020 (IRR 0.824, 95%CI 0.732–0.929) and rapidly

Abbreviations: ASR, age and sex-standardized rate; CCI, Charlson comorbidity index; CHD, coronary heart disease; CMS, clinical management system; COVID-19, coronavirus disease 2019; CVD, cardiovascular disease; ER, emergency room; HK HA, Hong Kong Hospital Authority; ICD-10, International Classification of Diseases, Tenth Revision; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; ICPC-2, International Classification of Primary Care, Second Edition; IRR, incidence rate ratio; KCDC, Korea center for disease control and prevention; KOSTAT, Korea national statistical office; MERS, Middle East respiratory syndrome; NHID, national health insurance data; NHIS, Korean national health insurance service; OECD, organisation for economic co-operation and development; RR, rate ratio; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; WHO, World Health Organization.

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rebounded to the pre-pandemic level in 2021 (IRR 1.049, 95%CI 0.915–1.203). In contrast, Korea showed a reversal of the pre-pandemic decline with CVD incidence increasing significantly in 2021 (IRR 1.108, 95%CI 0.996–1.015). Outpatient visits in Korea declined at the start of 2020 (IRR 0.890, 95%CI 0.826–0.958) and remained below expected levels through 2021, while Hong Kong showed no significant changes. Hospital admissions in Korea also declined significantly and did not recover.

Conclusion: The outbreak disrupted healthcare utilization among people with DM, leading to a temporary decline in CVD diagnoses. In Hong Kong, CVD incidence normalized in 2021, while in Korea, the continued increase in CVD incidence may be related to sustained care disruption.

1 | Introduction

In times of the COVID-19 pandemic, which started in February 2020, health systems confronted significant challenges, juggling a response to the crisis while ensuring the continued provision of essential health services. The World Health Organization (WHO) declared the end of the pandemic as a global health emergency on May 3, 2023, after 77 million confirmed cases with nearly 7 million deaths over those 3 years [1, 2]. Beyond the direct impact of severe acute respiratory syndrome coronavirus (SARS-CoV-2) infection and its health consequences, the pandemic's prolonged duration and scale led to widespread indirect impacts on disease burden. These impacts can be largely attributed to reductions in healthcare utilization driven by the strain on health systems and individual fear of contracting the virus [3, 4]. This is particularly concerning for individuals with chronic conditions like diabetes mellitus (DM), who rely on regular access to care for effective disease management [5–7]. Disruptions in routine care can result in significant negative prognoses.

Earlier research has reported reductions in healthcare utilization during periods of surging infection cases and stringent regulations [7–9], with variation depending on the pattern and severity of the pandemic waves, health system structure, and population characteristics. However, few studies have examined the differences in health outcomes and healthcare utilization, taking these variations into account, specifically among people with DM. Moreover, most studies have not fully captured the indirect impact of the pandemic, often overlooking the need to exclude the effect of the SARS-CoV-2 infection itself.

Our study aims to investigate and compare the indirect impact of the COVID-19 pandemic on all-cause mortality, cardiovascular disease (CVD), and healthcare utilization among people with DM from Korea and Hong Kong using population-based data and a closed-cohort study design. These two locations situated in East Asia, among the earliest affected by COVID-19 in the world, responded promptly and effectively starting in February 2020; however, the public health policies varied between the two locations in 2021, when Korea started to recover gradually from the stringent disease control, while Hong Kong enforced "dynamic zero-COVID-19" policy, similar with China's measures but less strict and more flexible without broad lockdowns (Supporting Information S1: 16). Therefore, by comparing the all-cause mortality and CVD incidence of people with DM from the two study locations during the pandemic, we may be able to provide a reference for policymakers in future public health crises.

2 | Methods

2.1 | Data Source

This is a retrospective, population-based cohort study analyzing two data sets from Korea and Hong Kong. The supporting documents provide the details of the two study locations (Supporting Information S1: 1).

For Korea, we obtained the data from the Korean National Health Insurance Services (NHIS) between January 1, 2014, and December 31, 2021. These data were linked to the COVID-19 database from the Korea Disease Control and Prevention Agency (KDCA) and the death database from the Korea National Statistical Office (KOSTAT). A 25.8% sample was selected from the entire population with a documented diagnosis of DM, using sex- and age-stratified random sampling (Supporting Information S1: 2). We collected SARS-CoV-2 infection data from the KDCA between January 1, 2020, and December 31, 2021 [10].

For Hong Kong, we retrieved data from the Hong Kong Hospital Authority Clinical Management System (HK HA CMS) between January 1, 2014, and December 31, 2021. These data were linked to the Hong Kong Death Registry and the laboratory-confirmed SARS-CoV-2 infection records (Supporting Information S1: 2).

2.2 | Study Population

Our study focused on individuals who were diagnosed with either type 1 or type 2 DM from January 1, 2014, to December 31, 2014. We used the International Classification of Primary Care, Second Edition (ICPC-2) and the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) for the Hong Kong cohort, while the Tenth Revision (ICD-10) was used for the Korean cohort to identify diagnoses of DM and CVD (included coronary heart disease, heart failure and stroke, Supporting Information S1: 3). Individuals with no prior history of CVD were included. We applied a 1-year washout period, excluding those who were diagnosed with CVD in 2014. The study followed a closed-cohort of eligible individuals from January

1, 2015, to December 31, 2021. Individuals who died or were laboratory-confirmed SARS-CoV-2 infection during the study period were censored during the follow-up period.

2.3 | Outcome Measures

The primary outcomes include all-cause, CVD-specific, and diabetes-specific (as the study population had diabetes mellitus, diabetes-specific mortality was defined as non-external-causes mortality, Supporting Information S1: 5) mortality and CVD incidence per 100,000 people (Supporting Information S1: 3). Additionally, secondary outcomes were the monthly rates of healthcare utilization per 1000 people, including outpatient visits, hospital admissions, emergency room visits, and the mean length of stay in the ward. To calculate rates, we divided the total counts of outpatient visits, hospital admissions, and emergency room visits by the total number of individuals for each month. For the mean length of stay in the ward, we took the total number of days stayed in the ward during a month and divided it by the number of admissions.

All rates were sex- and age-standardized to the Organization for Economic Co-operation and Development (OECD) 2021 population aged 20 years or older, ensuring that the rates are comparable between the two cohorts, despite differences in the distribution of age and sex.

2.4 | Analysis

Descriptive analyses provided the baseline (2015) characteristics of individuals with DM from the two cohorts and the monthly mean sex- and age-standardized rates of all-cause mortality, CVD, and healthcare utilization for each year from 2015 to 2021. To assess the impact of the pandemic on all-cause mortality, CVD, and healthcare utilization, interrupted time series analyses were performed, using a segmented quasi-Poisson regression model [11, 12] (Supporting Information S1: 6) as the variances of rates of interest were greater than their mean.

The overall observation period was divided into three subperiods: "pre-pandemic period" (months 1–61, January 2015–January 2020), "the first year of the pandemic" (months 62–74, February 2020–February 2021), and "the second year of the pandemic" (months 75–84, March 2021–December 2021). We set February 2020 as the beginning of the pandemic because both the Korean and Hong Kong governments began implementing COVID-19 measures following the first confirmed cases on January 20, 2020 and January 23, 2020, respectively. The second breakpoint was set in March 2021, when the pandemic situation became relatively controllable in both Korea and Hong Kong and coincided with the launch of vaccination programs at the end of February 2021 (Supporting Information S1: 17–18).

Additionally, we conducted subgroup analyses stratified by sex, age group (20–44, 45–64, ≥ 65), and Charlson Comorbidity Index (CCI: 0, 1, 2, ≥ 3) [13] (Supporting Information S1: 4). Age group was measured and applied each year, and CCI was calculated for the entire follow-up period. To improve the robustness of the findings, sensitivity analyses were performed to explore the influence of different seasonal patterns and to determine whether the results were dependent on the quasi-Poisson model used in the primary analysis. These included: (1) generalized linear models with log-transformed rates, adjusting for 3-, 6-, and 12-month period seasonality, and (2) adjustment for 6- and 12-month period seasonality. Additionally, Newey–West standard errors were employed to adjust for potential autocorrelation and heteroskedasticity [14].

We used $p < 0.05$ as the significance level and calculated a 95% confidence interval (CI). Analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, North, USA) and R 4.3.1 (R Core Team, Vienna, Austria).

3 | Results

A total of 1,228,685 individuals with DM were analyzed, with 926,230 from Korea and 302,455 from Hong Kong (Table 1). Males made up 51.0% in Korea and 47.4% in Hong Kong. In Korea, 42.6% of participants were aged 45–64, with 45.9% aged 65 or older; in Hong Kong, these age groups accounted for 42.8% and 53.0%, respectively. In Korea, 42.8% had a CCI score above 3, whereas in Hong Kong, 62.9% had a CCI score of 0. The mean follow-up period for both cohorts was 5.6 years. The means of monthly sex- and age-standardized rates of all-cause, CVD-specific, and diabetes-specific mortality, CVD incidence, and healthcare utilization in Korea and Hong Kong are presented in Supporting Information S1: 5.

3.1 | Indirect Impact of the COVID-19 Pandemic on All-Cause Mortality and CVD

Monthly age- and sex-standardized rates of all-cause mortality and CVD incidence between January 2015 and December 2021 are presented in Figure 1, and their relative changes during the pandemic are in Table 2.

During the first year of the pandemic, neither Korea nor Hong Kong exhibited significant changes in all-cause mortality rates. Both Korea and Hong Kong experienced an immediate reduction in CVD incidence following the outbreak in February 2020, though statistical significance was observed only in Hong Kong (IRR 0.824, 95% CI 0.732–0.929). Stratified analyses revealed a more pronounced impact on Hong Kong people among males (IRR 0.749, 95% CI 0.649–0.864), those aged 45–64 years (IRR 0.716, 95% CI 0.610–0.840), and patients whose $\text{CCI} = 1$ (IRR 0.819, 95%CI 0.680–0.987) (Supporting Information S1: 7–9). CVD incidence rebounded later in the first year and eventually returned to or exceeded the expected level in March 2021 (Hong Kong: IRR 1.049, 95% CI 0.915–1.203; Korea: IRR 1.108, 95% CI 1.039–1.182), especially females from Korea (IRR 1.178, 95% CI 1.081–1.284) (Supporting Information S1: 7). CVD incidence in Korea continuously increased during the pandemic period, reversing the pre-pandemic decline (Figure 1). Changes in CVD-specific mortality and diabetes-specific mortality are supplied in Supporting Information S1: 19 and 20. Both the all-cause

TABLE 1 | General characteristics of included subjects at baseline (2015).

Characteristics	Korea *N*	Korea (%)	Hong Kong *N*	Hong Kong (%)
Subjects	926,230	(100.0)	302,455	(100.0)
Sex				
Male	476,227	(51.4)	143,290	(47.4)
Female	450,003	(48.6)	159,165	(52.6)
Mean age (years and SD)	63.0	(12.9)	65.7	(12.2)
Age group				
20–44	72,618	(7.8)	12,597	(4.2)
45–64	428,174	(46.2)	129,471	(42.8)
≥ 65	425,438	(45.9)	160,387	(53.0)
Charlson Comorbidity Index				
0	176,055	(19.0)	184,975	(62.9)
1	166,350	(18.0)	52,067	(17.2)
2	186,987	(20.2)	30,730	(9.7)
≥ 3	396,838	(42.8)	34,683	(10.2)
Subjects in the following years				
2016	910,867	(98.3)	297,272	(98.3)
2017	895,401	(96.7)	291,517	(96.4)
2018	879,612	(95.0)	285,510	(94.4)
2019	862,881	(93.2)	279,162	(92.3)
2020	846,365	(91.4)	272,508	(90.1)
2021	827,988	(89.4)	264,946	(87.6)

mortality (IRR 1.013, 95%CI 1.001–1.026), CVD-specific mortality (IRR 1.087, 95%CI 1.038–1.137), and diabetes-specific mortality (IRR 1.013, 95%CI 1.000–1.026) in Hong Kong significantly increased during the second pandemic year.

3.2 | Indirect Impact of the COVID-19 Pandemic on Healthcare Utilization

Monthly sex- and age-standardized rates of healthcare utilization rates between January 2015 and December 2021 are presented in Figure 1 and Table 3. There was a notable difference in outpatient visit patterns between Korea and Hong Kong. In Korea, outpatient visits significantly declined immediately after the outbreak in February 2020 (IRR 0.890, 95% CI 0.826–0.958) and did not fully recover to expected levels during 2020 and 2021. In contrast, Hong Kong did not experience significant changes in outpatient visits during either year of the pandemic.

In Korea, hospital admissions dropped significantly in February 2020 (IRR 0.848, 95% CI 0.776–0.927) and remained low without a significant rebound in the second year. In Hong Kong, while there were no significant changes in hospital admission rates during the first year, a significant drop was observed at the beginning of the second year (IRR 0.889, 95% CI 0.825–0.959) along with an increase in the mean length of stay (IRR 1.211, 95% CI 1.077–1.360).

Emergency room visit patterns were different from outpatient visits or hospital admissions. In Korea, emergency room visits significantly declined following the outbreak in February 2020 (IRR 0.892, 95% CI 0.808–0.985), but returned to expected levels in the second year. In Hong Kong, in contrast, emergency room visits declined immediately (IRR 0.849, 95% CI 0.767–0.939) and remained below expected levels during the second year. Two sensitivity analyses using linear model and quasi-Poisson model with seasonality adjustment for 6 and 12 months) yielded consistent results (Supporting Information S1: 10–13).

Changes in diabetes-specific healthcare utilization are shown in Supporting Information S1: 19 and 20. Both the diabetes-specific outpatient visits and hospital admissions showed similar patterns to all-cause utilization in Hong Kong, accounting for approximately 14.3%–36.5% of the total (Supporting Information S1: 5).

4 | Discussion

This is a comparative study to assess the indirect impact on mortality, CVD incidence, and healthcare utilization among people with DM from Korea and Hong Kong, focusing on

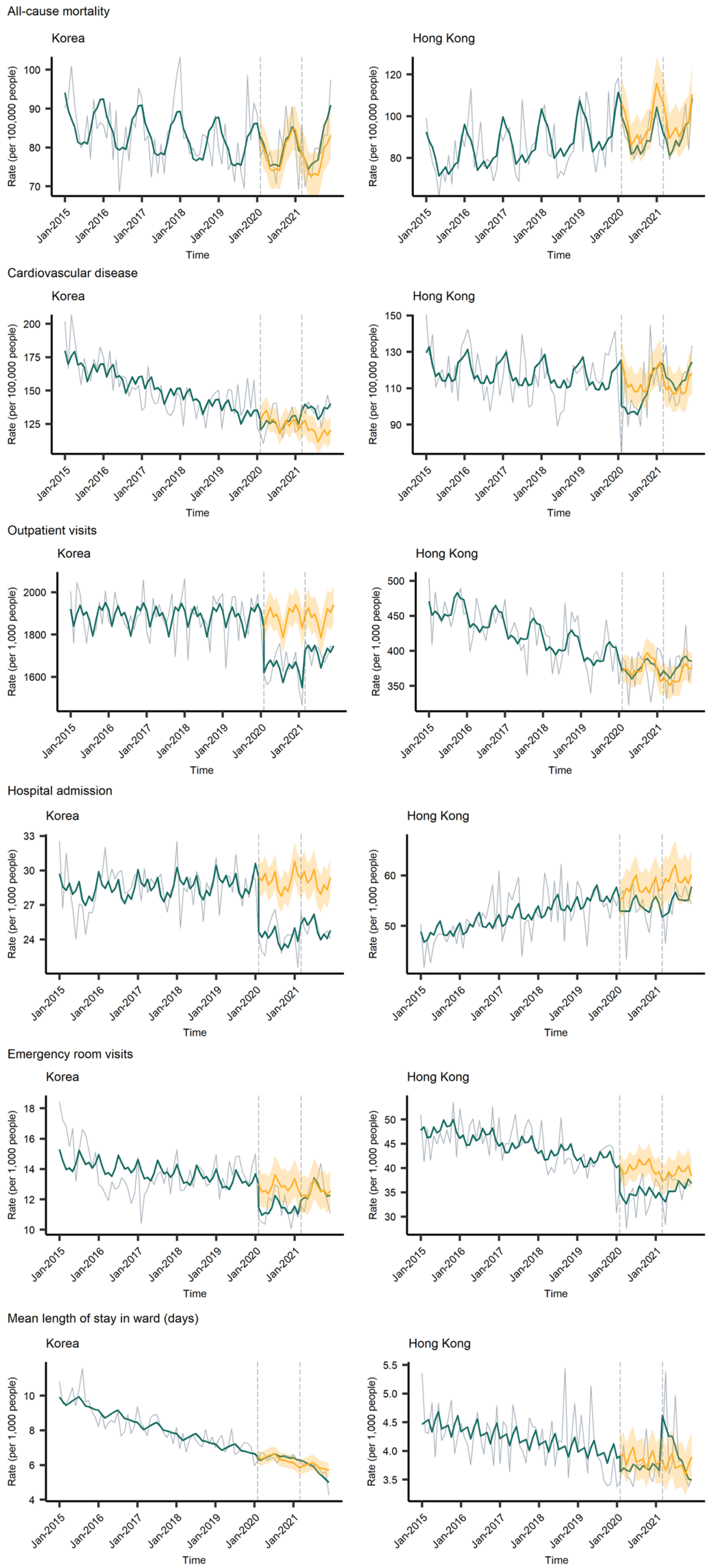

FIGURE 1 | Changes in age- and sex-standardized rates for all-cause mortality, CVD incidence, and healthcare utilization between the pre-pandemic period, the first and second year of the pandemic, among people with diabetes mellitus from Korea and Hong Kong. *Note:* The grey lines are the monthly incidence rate (observed). The vertical lines represent the beginning of the COVID-19 pandemic (starting from February 2020) and the beginning of the second year of the pandemic period (starting from March 2021). The green solid line is the fitted trend line with seasonality adjustment, and the yellow line is the predicted trend (counterfactual) based on the pre-pandemic data. Shadows show the 95% CIs. Lag (Emergency department visit in Korea) = 1, other lags = 0.

TABLE 2 | Changes in age- and sex-standardized rates per 100,000 people for all-cause mortality and CVD incidence between the pre-pandemic period, first year of the pandemic period, and second year of the pandemic period among patients with diabetes mellitus from Korea and Hong Kong.

	Korea			Hong Kong		
Outcomes	**IRR**	**(95% CI)**	***p* value**	**IRR**	**(95% CI)**	***p* value**
All-cause mortality						
Pre-pandemic period: trend (β1)	0.998	(0.997–0.999)	0.002	1.003	(1.002–1.004)	< 0.001
First year of the pandemic period: level (β2)	1.024	(0.952–1.102)	0.519	0.965	(0.890–1.046)	0.386
First year of the pandemic period: trend (β3)	0.998	(0.985–1.011)	0.744	0.995	(0.982–1.008)	0.454
Second year of the pandemic period: level (β4)	1.009	(0.941–1.082)	0.809	0.886	(0.814–0.964)	0.005
Second year of the pandemic period: trend (β5)	1.008	(0.997–1.020)	0.148	1.013	(1.001–1.026)	0.041
CVD incidence						
Pre-pandemic period: trend (β1)	0.995	(0.994–0.996)	< 0.001	0.999	(0.997–1.001)	0.249
First year of the pandemic period: level (β2)	0.947	(0.831–1.078)	0.407	0.824	(0.732–0.929)	0.001
First year of the pandemic period: trend (β3)	1.008	(0.994–1.022)	0.268	1.019	(1.002–1.037)	0.027
Second year of the pandemic period: level (β4)	1.108	(1.039–1.182)	0.002	1.049	(0.915–1.203)	0.493
Second year of the pandemic period: trend (β5)	1.005	(0.996–1.015)	0.275	0.999	(0.982–1.015)	0.887

Note: Rates were age- and sex-standardized to the OECD 2021 population. Beta coefficients (β1–β5) were estimated using segmented quasi-Poisson regression models adjusting for seasonality (3-, 6- and 12-month periods). "Pre-pandemic period" (January 2015–January 2020), "First year of the pandemic period" (February 2020–February 2021) and "Second year of the pandemic period" (March 2021–December 2021). CVD, Cardiovascular diseases, including coronary heart disease, stroke, and heart failure; IRR, incidence rate ratio; CI, confidence interval. Newey–West standard errors were applied to adjust for potential autocorrelation and heteroskedasticity. All lags = 0.

individuals without confirmed COVID-19 infection. Using population-based health data, our findings revealed significant changes in CVD incidence and healthcare utilization during the pandemic in both settings, similar to findings from other countries [15–17]. In 2021, as Korea began relaxing its COVID-19 policies while Hong Kong flexibly adjusted restrictions according to the transmission rate (Supporting Information S1: 14–16), differences in indirect impacts became more evident, likely reflecting differences in the recovery of healthcare utilization, which remained slower in Korea than in Hong Kong.

The abrupt drop in CVD incidence rates observed in both Korea and Hong Kong following the initial outbreak of the pandemic is likely attributable to patients avoiding or delaying in seeking care, deferrals or cancellations of preventive care services, such as examination or screening, and limited access to in-person care during the acute phases of the pandemic [18–20]. As the situation gradually stabilized in mid-2020 (Supporting Information S1: 17–18), efforts to catch up on the backlogged services contributed to the rebound in CVD diagnoses.

In Hong Kong, CVD incidence stayed stable after catching up to pre-pandemic levels in 2021. The short-term decline followed by a rebound could be a temporary substitution effect, whereby diagnoses were deferred diagnoses during the early pandemic period but captured in subsequent months, rather than indicating a true change in underlying disease incidence trend. This pattern may be explained by relatively stable access to in-person outpatient care during the pandemic, alongside government strategies such as a proxy prescription refill and expanded telemedicine services [21] to support medication adherence and chronic disease management. Moreover, the sudden drop in CVD incidence in the first year following the upward CVD-specific mortality trend during the second pandemic year in Hong Kong, may indicate the negative impact of missed diagnosis of CVD.

In contrast, findings from Korea showed a different pattern, CVD incidence reversing its pre-pandemic decline and continuing to rise in 2021. This trend suggests a more pronounced negative indirect impact of the pandemic on people with DM. This may be linked to the substantial and prolonged reductions in outpatient visits and hospital admissions, which recovered more slowly compared to Hong Kong. Notably, the sustained increase in CVD incidence in Korea beyond 2021 raises concern about possible long-term consequences of disrupted care. While supporting care strategies such as telehealth services and long-term prescriptions [22] were implemented to maintain treatment continuity, reduced access to routine in-person care could have impaired key aspects of diabetes management, particularly blood glucose and lipid monitoring [23] and timely regimen adjustment, thereby increasing the risk of diabetic complications such as CVD.

In contrast to studies that reported an increase in deaths among people with DM during the pandemic [24–26], our findings did not reveal significant changes in the level of all-cause mortality and CVD-specific mortality rates but significant trend changes during the second year of the pandemic period found in Hong Kong, suggesting a potential lag effect of the delays in detecting and treating CVD and diabetic complications on prognosis of diabetic population, and raising concerns that the full extent of these delayed health effects may become apparent in the coming years [27]. It can be explained by our study focused on the non-COVID-19 population, minimizing the effect of SARS-CoV-2 infection on mortality risk among people with diabetes [28, 29]. Further research is needed to fully understand the long-term indirect impact of the COVID-19 pandemic on health outcomes and healthcare utilization among people with DM.

TABLE 3 | Changes in age- and sex-standardized rates per 1000 people for healthcare utilization between the pre-pandemic period, first year of the pandemic period, and second year of the pandemic period among patients with diabetes mellitus from Korea and Hong Kong.

	Korea			Hong Kong		
Outcomes	**RR**	**(95% CI)**	***p* value**	**RR**	**(95% CI)**	***p* value**
Outpatient visit						
Pre-pandemic period: trend (β1)	1.000	(0.999–1.000)	0.641	0.997	(0.996–0.998)	< 0.001
First year of the pandemic period: level (β2)	0.890	(0.826–0.958)	0.002	0.986	(0.920–1.057)	0.692
First year of the pandemic period: trend (β3)	0.997	(0.987–1.006)	0.466	1.001	(0.987–1.015)	0.923
Second year of the pandemic period: level (β4)	0.925	(0.888–0.963)	< 0.001	1.025	(0.969–1.085)	0.387
Second year of the pandemic period: trend (β5)	0.997	(0.992–1.003)	0.287	1.002	(0.994–1.010)	0.636
Hospital admission						
Pre-pandemic period: trend (β1)	1.000	(0.999–1.001)	0.425	1.003	(1.002–1.004)	< 0.001
First year of the pandemic period: level (β2)	0.848	(0.776–0.927)	< 0.001	0.940	(0.865–1.022)	0.150
First year of the pandemic period: trend (β3)	0.997	(0.985–1.009)	0.600	1.000	(0.989–1.010)	0.936
Second year of the pandemic period: level (β4)	0.883	(0.839–0.929)	< 0.001	0.889	(0.825–0.959)	0.002
Second year of the pandemic period: trend (β5)	0.995	(0.988–1.002)	0.133	1.008	(0.997–1.019)	0.150
Emergency department visit						
Pre-pandemic period: trend (β1)	0.998	(0.996–1.000)	0.053	0.997	(0.996–0.998)	< 0.001
First year of the pandemic period: level (β2)	0.892	(0.808–0.985)	0.024	0.849	(0.767–0.939)	0.002
First year of the pandemic period: trend (β3)	0.999	(0.988–1.010)	0.820	1.002	(0.988–1.017)	0.746
Second year of the pandemic period: level (β4)	0.992	(0.863–1.140)	0.912	0.886	(0.801–0.981)	0.019
Second year of the pandemic period: trend (β5)	1.000	(0.964–1.038)	0.992	1.007	(0.995–1.020)	0.256
Mean length-of-stay in ward (days)						
Pre-pandemic period: trend (β1)	0.993	(0.992–0.994)	< 0.001	0.998	(0.996–0.999)	0.001
First year of the pandemic period: level (β2)	0.977	(0.918–1.040)	0.468	0.940	(0.870–1.016)	0.120
First year of the pandemic period: trend (β3)	1.006	(1.000–1.013)	0.044	1.003	(0.995–1.011)	0.435
Second year of the pandemic period: level (β4)	1.067	(1.004–1.134)	0.038	1.211	(1.077–1.360)	0.001
Second year of the pandemic period: trend (β5)	0.979	(0.972–0.986)	< 0.001	0.970	(0.958–0.983)	< 0.001

Note: Rates were age- and sex-standardized to the OECD 2021 population. Beta coefficients (β1–β5) were estimated using segmented quasi-Poisson regression models adjusting for seasonality (3-, 6- and 12-month periods). "Pre-pandemic period" (January 2015–January 2020), "First year of the pandemic period" (February 2020–February 2021) and "Second year of the pandemic period" (March 2021–December 2021). RR, Rate Ratio; CI, confidence interval. Newey–West standard errors were applied to adjust for potential autocorrelation and heteroskedasticity. Lag (Emergency department visit in Korea) = 1, other lags = 0.

The immediate decline in overall healthcare utilization, especially in emergency rooms, which were the frontline facilities for COVID-19, among people with DM when the pandemic started, is consistent with findings from other studies in the general population [30–32]. Despite efforts to maintain service provision in both locations [33, 34], Hong Kong did not experience a significant reduction in outpatient visits throughout the pandemic periods, in contrast to Korea, which could be explained by Hong Kong's relatively small number of COVID-19 cases and a flatter epidemic curve, especially in 2021 (Supporting Information S1: 17–18). The fear of cross-infection may prevent people with diabetes from seeking care.

Our study has several limitations. First, data from Hong Kong were limited to the public sector, which may not fully capture the healthcare utilization of the entire population with DM. However, the public sector in Hong Kong covers most chronic disease patients, allowing a meaningful analysis of trends. Second, excluding individuals from the analysis when they had confirmed infections could introduce time-varying selection bias, particularly if infection risk is associated with individual health status, such as frailty, potentially altering population composition over time. To mitigate this, we applied a closed cohort and standardized rates. Third, our analysis did not account for alternative care options, such as telemedicine or a proxy refill strategy, which may have influenced utilization patterns. Fourth, we were unable to examine cause-specific mortality or healthcare utilization related to DM or CVD in the Korean population because we could not access the relevant data, but the findings from Hong Kong might serve as a reference for Korea. This limits our ability to directly link changes in complication rates or service use to mortality outcomes. Future research should explore these gaps using cause-specific indicators. Lastly, the analysis did not cover the Omicron wave in early 2022, during which both countries experienced significant surges in COVID-19 cases (Supporting Information S1: 14).

Despite these limitations, our study specifically targeted the indirect impact of the pandemic by excluding people infected with COVID-19, thereby eliminating healthcare utilization and outcomes unrelated to direct SARS-CoV-2 infections. In both Korea and Hong Kong, COVID-19 testing was widely accessible and centrally coordinated by public health authorities, ensuring rapid contact tracing and comprehensive capture of infection records. This minimized the likelihood of undetected infections in our study cohort and supports the validity of our non-COVID-19 population. We focused on individuals with pre-existing DM and used a closed-cohort approach to assess the changes in all-cause mortality, CVD, and healthcare utilization over time, providing a more precise assessment of the impact of the pandemic.

In conclusion, our findings confirmed that the first outbreak disrupted healthcare utilization among people with DM, leading to a sudden decline in CVD incidence. The sustained higher-than-expected CVD incidence in Korea in 2021 raised concern about increased CVD risk due to prolonged interrupted in-person visits to care. The different changes in CVD incidence in 2021 in Korea and Hong Kong reflect the importance of maintaining access to in-person care to mitigate the indirect impact of the pandemic. Our study calls for further research to comprehensively evaluate the long-term indirect impacts of the pandemic on people with DM and to support ongoing efforts to enhance the resilience of health systems in preparation for future health crises.

Author Contributions

Hin Moi Youn: writing – original draft, methodology, visualization, formal analysis. **Zhuoran Hu:** writing – original draft, methodology, validation, visualization, formal analysis. **Yu Shin Park:** writing – review and editing, visualization, methodology, formal analysis. **Jianchao Quan:** writing – review and editing, supervision, funding acquisition, conceptualization. **Cindy Lo Kuen Lam:** funding acquisition, writing – review and editing, supervision, conceptualization. **Eun Cheol Park:** conceptualization, funding acquisition, writing – review and editing, supervision. **Eric Yuk Fai Wan:** conceptualization, funding acquisition, writing – review and editing, visualization, project administration, supervision.

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Ethics Statement

This study was approved by the Severance Hospital Institutional Review Board (IRB No. 4-2022-0248) and the Institutional Review Board of the University of Hong Kong Hospital Authority Hong Kong West Cluster (ref.: UW 21-297).

Conflicts of Interest

E.Y.F.W. has received research grants from the Health Bureau of the Government of the Hong Kong SAR, the Hong Kong Research Grants Council of the Government of the Hong Kong SAR, Narcotics Division, Security Bureau of the Government of the Hong Kong SAR, and National Natural Science Foundation of China, outside the submitted work. C.L.K.L. has received research grants from the Health Bureau of the Government of the Hong Kong SAR, conference grants from the Hong Kong College of Family Physicians and honoraria from the World Organization of Family Doctors, the Academy of Family Physicians of Malaysia and the International Association of Chinese Nephrologists, outside the submitted work. H.M.Y., Z.H., Y.S.P., J.Q., and E.C.P. declared no conflicts of interest.

Data Availability Statement

Research data are not shared. Data will not be made available to others because the data custodians have not given permission.

Transparency Statement

The corresponding authors, Eun Cheol Park and Eric Yuk Fai Wan affirm that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.
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