BMJ Open

Long-term spill-over impact of COVID-19 on health and healthcare of people with non-communicable diseases: a study protocol for a population-based cohort and health economic study

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To cite: Youn HM, Quan J, Mak IL, *et al*. Long-term spill-over impact of COVID-19 on health and healthcare of people with non-communicable diseases: a study protocol for a population-based cohort and health economic study. *BMJ Open* 2022;**12**:e063150. doi:10.1136/bmjopen-2022-063150

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2022-063150).

Received 29 March 2022
Accepted 19 July 2022

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ABSTRACT

Introduction The COVID-19 pandemic has a significant spill-over effect on people with non-communicable diseases (NCDs) over the long term, beyond the direct effect of COVID-19 infection. Evaluating changes in health outcomes, health service use and costs can provide evidence to optimise care for people with NCDs during and after the pandemic, and to better prepare outbreak responses in the future.

Methods and analysis This is a population-based cohort study using electronic health records of the Hong Kong Hospital Authority (HA) CMS, economic modelling and serial cross-sectional surveys on health service use. This study includes people aged ≥18 years who have a documented diagnosis of diabetes mellitus, hypertension, cardiovascular disease, cancer, chronic respiratory disease or chronic kidney disease with at least one attendance at the HA hospital or clinic between 1 January 2010 and 31 December 2019, and without COVID-19 infection. Changes in all-cause mortality, disease-specific outcomes, and health services use rates and costs will be assessed between pre-COVID-19 and-post-COVID-19 pandemic or during each wave using an interrupted time series analysis. The long-term health economic impact of healthcare disruptions during the COVID-19 pandemic will be studied using microsimulation modelling. Multivariable Cox proportional hazards regression and Poisson/negative binomial regression will be used to evaluate the effect of different modes of supplementary care on health outcomes.

Ethics and dissemination The study was approved by the institutional review board of the University of Hong Kong, the HA Hong Kong West Cluster (reference number UW 21–297). The study findings will be disseminated through peer-reviewed publications and international conferences.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ A large, retrospective population-based cohort study of people with major non-communicable diseases reflecting the real-world setting of Hong Kong with its zero COVID-19 policy.
⇒ Comprehensive individual-level data to analyse health outcomes and health service use collected from linked clinical records, death and cancer registries, and serial cross-sectional surveys.
⇒ In-depth outcome measures before and after several waves of COVID-19 outbreaks at several time points will provide information to understand the short-term and long-term indirect impacts of COVID-19.
⇒ Diagnosis coding in clinical records may be misclassified or incomplete.
⇒ Self-reporting bias such as recall bias may present in survey data.

INTRODUCTION

The COVID-19 pandemic caused by SARS-CoV-2 has placed the world and healthcare systems under unprecedented strain. While the majority of studies have focused on COVID-19 infection rates, hospitalisations and deaths, the true toll of the pandemic extends beyond the direct morbidity and mortality from SARS-CoV-2 infection. By January 2022, over 1 million excess deaths occurred in the USA alone; while COVID-19 was documented as a primary or underlying cause for 901 422 deaths, an estimated 11% of excess deaths were indirectly related to COVID-19 infection.[1 2] Globally, 2.5 million excess deaths were directly and indirectly

attributed to COVID-19 from January 2020 to June 2021 in Organisation of Economic Co-operation and Development countries, representing a 16% increase in the expected number of deaths.[3] Most excess non-COVID-19 deaths (78%) in the USA occurred in subjects 25–64 years old, with the most common causes of death being diabetes mellitus, heart disease and Alzheimer's disease.[4]

Implementation of strict infection prevention and control measures and the reallocation of healthcare resources to emergency COVID-19 care have adversely affected usual care for non-communicable diseases (NCDs).[5] Two rounds of global assessment by the WHO presented that the percentage of surveyed countries reporting partial or complete disruptions to NCDs services were approximately 60% in 2020 and 50% in 2021.[5 6] During the first year of the pandemic in 2020, only 17% of high-income countries had allocated additional government funding to NCD services as part of a national COVID-19 response plan.[5]

People with NCDs are more vulnerable to serious morbidity and mortality affected directly and indirectly by COVID-19. Service disruptions from cancellation of elective care, redirection of medical resources and reluctance of people with NCDs in seeking healthcare for fear of COVID-19 exposure pose new challenges in the management of NCDs. The 'spill-over' effect, commonly used in health economics, refers to the indirect impact on individuals who were not infected with COVID-19 but nonetheless are affected for better or worse.[7] The COVID-19 pandemic is likely to have a significant spill-over impact on NCD-related morbidity and mortality over the long term, beyond the direct effects of COVID-19 infection.

Steep declines in non-COVID-19 emergency department (ED) attendances are consistently observed around the world.[8–15] ED attendances for myocardial infarction, stroke and hyperglycaemic crisis declined by 23%, 20% and 10%, respectively, in the 10 weeks following the emergency declaration in the USA.[8] Despite the relatively low number of COVID-19 cases in Greece, cardiology ED attendances fell by 60% at the COVID-19 outbreak period, yet a rebound increase was observed post lockdown, such that cumulative attendances after the lockdown exceeded those during and before the outbreak.[16] Evidence of excess mortality, out-of-hospital cardiac arrests[17] and calls to emergency phone lines[18] fuel growing concerns of the adverse impact of COVID-19 on the quality of care for people with NCDs. Quantifying and characterising changes in health outcomes, health service use and costs can help health systems to optimise care for people with NCDs during and after the pandemic and to better prepare outbreak response in the future.

Hong Kong, one of the most densely populated cities in the World, had its first wave of COVID-19 outbreaks in late January 2020. By March 2022, it has had four major waves of outbreaks and is currently experiencing the fifth wave. The Hong Kong SAR government, shaped by the 2003 SARS experience, took swift and decisive actions, aided by heightened public awareness and high compliance with public health precautions. Hong Kong, in keeping with mainland China, adopted a stringent containment policy, 'zero COVID-19', implementing rapid lockdowns, universal isolation of all confirmed cases in hospitals or other facilities, social distancing, contact tracing, mass screening, travel bans and strict quarantine for travellers. As a result, prior to the start of the fifth wave, it maintained one of the lowest COVID-19 infection numbers and deaths per capita in the world during the first four waves of outbreaks up to January 2022,[19] with zero locally transmitted infections for almost 8 months between the fourth wave (early May 2021) and the fifth wave (early January 2022). However, Hong Kong has experienced the worst outbreak, with over 50 000 daily infection cases in early March 2022 and a total of over 700 000 cumulative cases since the fifth wave began. The rapid growth of cases has required drastic diversion of public health services, including designated hospitals and clinics for the exclusive care of patients with COVID-19, at the expense of reduction of usual care of NCD.

Since the pandemic began, scattered local reports have emerged on disrupted care for people with stroke,[20] diabetes mellitus[21] and cancer.[22] There was a notable reduction in the volume of activities across a wide range of services provided by the publicly funded Hong Kong Hospital Authority (HA), which provided over 90% inpatient care in the territory.[23] This service reduction could overwhelm health services in the future when the pandemic recedes, if people with NCDs present with more advanced disease and/or complications that are more difficult and costly to treat. Even modest delays in surgery for cancer are detrimental to survival:[24] a 4-week delay of cancer treatment is associated with increased mortality of 4%–8%.[25] The downstream effects of disrupted care on people with NCDs could be substantial in terms of life-years lost and quality of life, along with the extra healthcare costs of treating advanced diseases and additional complications.

A comprehensive investigation of the spill-over impact of COVID-19 on the healthcare of the entire population with NCDs is lacking. Compared with prior studies in other countries, Hong Kong, with its unique and stringent COVID-19 policy and low rates of infection, particularly during the first 2 years before the fifth wave, would allow us to estimate the 'true' indirect effects. For example, it will help to assess the postoutbreak rebound of health and health service use during the interwave periods without contamination. Addressing barriers to healthcare and maintaining the quality of care are central to strengthening the resilience of our healthcare system amidst the healthcare crisis. We need to urgently explore alternative modes of supplementary care and to examine how they affect health outcomes and health service use for people with NCDs.

Aims and objectives

This study aims to evaluate the spill-over impact of the COVID-19 outbreak on health outcomes, health service

use and costs in people with major NCDs. We will carry out two phases of analysis to measure both the short-term and long-term impacts of the COVID-19 outbreak. We will include the six leading NCDs (diabetes mellitus, hypertension, cardiovascular diseases (CVDs), cancer, chronic kidney diseases (CKDs) and chronic respiratory diseases) that represent the most prevalent conditions and the major causes of deaths in Hong Kong. The study objectives are

- To determine changes in all-cause mortality, disease-specific outcomes, and health service use rates and costs among people with major NCDs during the prewave, postwave and interwave periods of the COVID-19 outbreak.
- To assess the long-term health economic impact of COVID-19 on health outcomes and health service use rates and costs among people with major NCDs by conducting an in-depth economic evaluation.
- To explore the impact of different modes of care on all-cause mortality, disease-specific outcomes, and health service use rates and costs among people with major NCDs during the post-COVID-19 period.

METHODS AND ANALYSIS

Study design

This study consists of two parts. First, a retrospective cohort study using data extracted from the electronic medical records of the Hong Kong HA clinical management system (CMS) from 1 January 2010 to 31 December 2024. We defined a long pre-COVID-19 period to collect information on key factors including duration of disease, history of comorbidities and secular patterns of health service use prior to the outbreak. We extended the observation period of the post-COVID-19 period to 5 years, from 2020 to 2024, allowing sufficient time to assess disease outcome in the long term, such as incidence of complications or deaths. The data collection is retrospective, but the observation period is bidirectional. We will apply economic modelling using individual-level microsimulation to assess population-level outcomes and costs. Second, we will carry out two serial cross-sectional surveys on self-reported health service use in 2020 and 2023 to estimate the distribution of public and private health service use among people with NCDs.

Subjects

Cohort study

The cohort study included people aged 18 and above with a documented diagnosis of diabetes mellitus, hypertension, CVD, cancer, CKD or chronic respiratory disease with at least one attendance at HA hospital, general or specialist outpatients clinic between 1 January 2010 and 30 June 2024. As this study focuses on the indirect impact of COVID-19, people with a documented diagnosis of COVID-19 during the study period will be excluded.

Cross-sectional survey

People aged 18 and above with a documented diagnosis of diabetes mellitus, hypertension, CVD, cancer, CKD or chronic respiratory disease who attended public general or specialist outpatient clinics are eligible to participate. All participants are able to communicate in either Chinese or English, and provide informed consent. People with a documented diagnosis of COVID-19 during the study period will be excluded.

Sample size calculation

Cohort study

For the cohort study, the primary outcome of the study is the difference in all-cause mortality between the pre-COVID-19 and post-COVID-19 outbreak periods among people with major NCDs in Hong Kong. The change in mortality rate during the COVID-19 period ranged from 0% to 133% in general populations around the world.[26] In Hong Kong, the average annual all-cause mortality rate in people with diabetes was around 1.5 per 100 person-years.[27] Using a conservative assumption of a 5% relative increase in mortality rate between the pre-COVID-19 and post-COVID-19 outbreaks, a total of 239 540 people is needed to detect the difference at 80% power and 5% level of significance.[28 29]

Cross-sectional survey

Using the data collected from the Hong Kong Population Health Survey (PHS) 2014/2015 conducted by the Department of Health, we found that 27.5% of people with NCDs had used private outpatient consultation and hospital services in the 12 months preceding the survey. Based on a conservative assumption of a 10% difference, 684 people will be needed to achieve 80% power and 5% level of significance.[30] Considering the attrition rate of 50% at follow-up survey, a total of 977 people will be needed.

Data collection

Cohort study

Anonymous data including sociodemographics, disease-specific clinical parameters including disease duration, control and treatment modalities, health service use rates, comorbidities including complications identified by International Classification of Primary Care, Second Edition (ICPC-2) and the International Classification of Diseases, Ninth revision, Clinical Modification (ICD-9-CM) diagnosis codes and death data from the Hong Kong Death Registry of all cohort subjects will be extracted from the HA CMS database (online supplemental file 1A). Two phases of data extraction will be conducted for the data collected in the periods January 2010–April 2022 and January 2022–June 2024 to evaluate the immediate and long-term impacts of the COVID-19 outbreak on the care of people with NCDs. We use HA/Hong Kong Cancer Registry (HKCaR) data on people diagnosed with cancer, including a number of people with cancer, cancer stage

at diagnosis, and age-stratified and stage-stratified survival data.

Cross-sectional survey

Two surveys will be conducted for people with the major NCDs recruited from general outpatient clinics (GOPCs) and specialist outpatient clinics (SOPCs) to collect data on health service use patterns and rates in 2020 and 2023. The questionnaire was adopted from those used in the Government of Hong Kong Population Survey and our previous in-depth cost analysis studies on HA primary care patients with hypertension and diabetes mellitus[31–34] (online supplemental file 1B). People will be approached for eligibility and participation in the study by qualified research conductors face-to-face at GOPC and SOPC, and those who reported they have a disease specified in this study and provided consent to participate will be included in the survey. We will conduct the diagnosis screening by cross-checking with each participant's CMS records to confirm the eligibility for the study.

COVID-19 outbreaks

The study intervention is the COVID-19 outbreak in Hong Kong. The pre-COVID-19 and post-COVID-19 outbreak periods will be defined as 1 January 2010–31 December 2019 and 1 January 2020–31 December 2024, respectively. Additionally, we will consider Hong Kong's multiple waves of COVID-19 outbreak periods during which different magnitudes of infections and government restrictions are observed.

Outcome measures

Health outcomes

The primary health outcome is the incidence of all-cause mortality among people with major NCDs during the post-COVID-19 period. The secondary outcomes are disease-specific outcomes including incidence of complications and severity. Complications include CVD, end-stage renal disease, stage of cancer, acute exacerbations of COPD and asthma, and non-COVID-19 pneumonia. Severity indicators include haemoglobin A1C, blood pressure (BP), estimated glomerular filtration rate and others (online supplemental file 1C).

Health service use

Use rates and costs for public and private health services including hospitalisation (episodes, modes of admission and length of stay), specialist and general outpatient consultations (number of visits, modes of consultations and Western/Chinese medicine), and Accident & Emergency Department (AED) attendances. We will estimate healthcare costs using the listed prices of health services from the HA Gazette for the evaluation of economic impact. The HA ordinance (chapter 113) provides listed prices of treatment and investigation, which is the best available service unit costs.[35]

Burden of diseases due to the spill-over effect of COVID-19

The primary outcome of health economic evaluation is years of life lost (YLLs). In this study, we estimate YLL, quality-adjusted life year (QALY) and disability-adjusted life year (DALY) attributable to delayed care resulting from the COVID-19 outbreak. Based on life expectancy for 10-year age groups from the Census and Statistics Department life tables for 2017–2019, we will calculate average life-years lost under the scenario or standard versus delayed care.

Data analysis plan

- To determine changes in all-cause mortality, disease-specific outcomes and health service use rates and costs among people with major NCDs before and after the COVID-19 outbreak (objective 1).

We calculate descriptive statistics on the annual incidence of all-cause mortality and disease specific outcomes, and public health service use rates in each year between 2010 and 2024. Three 5-year periods (2010-2014, 2015-2019 and 2020-2024) will be used to investigate the historical trend, pre-COVID-19 and post-COVID-19 outbreak periods, respectively. We will perform the χ^2 test and analysis of variance to compare the average annual incidence and the changes in the rates of each outcome between these periods. Multiple imputation chained equation (MICE) method will be used to prevent potential bias. Each missing value will be imputed five times based on all baseline characteristics, and outcomes with results will be pooled according to Robin's rule.[36] An interrupted time series analysis will be used to evaluate the changes in all-cause mortality and each disease-specific outcome between pre-COVID-19 and post-COVID-19 periods.[37] Mortality and disease-specific outcomes will be estimated as counts of deaths or occurrences using Poisson regression, with the log of the total population size as an offset, or negative binomial regression in the presence of overdispersion. Similarly, health service use rates will be assessed using the same method. Additionally, we may conduct further analysis to capture the variations in impact of varying waves of COVID-19 during the study period.

As for the cross-sectional study, descriptive statistics will be used to summarise all public and private health service use. The private and public proportions of total health service use rates and costs will be calculated and compared with those obtained from the Hong Kong PHS 2014/2015 conducted by the Department of Health. Generalised linear model with a logit link and the binomial family adjusted with participants' characteristics will be conducted to evaluate the difference in private and public proportions of total health service use between pre-COVID-19 and post- COVID-19 periods.

- To assess the long-term health economic impact of COVID-19 on health outcomes and health service use rates and costs among people with major NCDs by conducting an in-depth economic evaluation (objective 2).

We will assess the immediate impact of COVID-19 outbreak on health service use using an interrupted time series analysis during the early period of COVID-19 outbreak. For a long-term impact evaluation, we adopt a

comparative risk approach using individual-level microsimulation to assess differences in population-level outcomes and costs.

For cancer, we apply a discrete-event simulation model to estimate overall survival, cancer-specific and stage-specific risks of death using HKCaR data. By each cancer type, we fit Cox proportional hazards and Fine and Gray[38] competing risk regression models to estimate all-cause and cancer-specific mortality respectively, stratified by year of diagnosis. Model covariates include age, sex, disease severity (stage and Elixhauser comorbidities), district, smoking status and income. For each subject, we calculate time to any cancer treatment from diagnosis on waiting time (day) from decision to treat to start of radiotherapy and waiting time (day) for receiving first treatment after diagnosis for people with cancer requiring radical radiotherapy. To examine the impact on overall survival from delayed care, we estimate per-week HRs associated with delay for each cancer type and stage. Based on 2010–2019 health service volume data, we estimate the total number of deaths, YLL, QALY and DALY attributable to delayed care. We based life expectancy for 10-year age groups from the Census and Statistics Department life tables for 2017–2019 to calculate average life-years lost per subject under the scenario of standard versus delayed care.

For non-oncological conditions, we assess how changes in surrogate biomarkers during COVID-19 disruptions impact on future health outcomes over the subject lifetime. Our base case for comparison is biomarker trajectories under standard care before COVID-19. We use individual-level discrete time models at intervals of 6 or 12 months by applying observed time-varying biomarker changes (hemoglobin A1c (HbA1c), blood pressure (BP), lipids and urine albumin to creatinine ratio (ACR)) at 6 monthly intervals to model two scenarios: (1) a short duration of 12–24 months before reverting to standard care and (2) a sustained change in biomarkers relative to standard care. We use the simulation models for diabetes, heart and kidney diseases validated for the local population. To fit the survival curves for our simulation over a long-term time horizon, the parametric form of the underlying hazard will be examined graphically, and model distributions (exponential, log-logistic and log-normal) will be selected by Akaike's Information Criterion (AIC). We plot survival over time for both immediate treatment and delayed treatment groups running the simulation model to estimate lifetime health outcomes and healthcare costs.

We group our retrospective cohort of people with NCDs into pre-existing and incident NCDs during the COVID-19 outbreak (2020–2021) and people with NCDs before the COVID-19 period (2015–2019). We compare the pre-COVID-19 and COVID-19 period groups to assess the observed changes in mortality rates, complication rates and healthcare costs over the long term (follow-up to 2024). We apply HA Gazette unit costs to derive the annual cost of health service use, supplemented with published data on the unit costs of treating each complication where necessary. We fit Cox proportional hazard models to compare time-to-event for each complication and mortality. We fit generalised linear model (GLM) regression models with gamma distribution to the actual and predicted healthcare costs for the pre-COVID-19 and COVID-19 period groups to assess differences in average annual cost per subject. We will validate the projections of our simulation models against the observed data (follow-up to 2024) to assess any temporal changes post-COVID-19 in patient risks and outcomes. We update and recalibrate the survival curves in our risk models (if necessary) to rerun the simulation model over 20 years to estimate lifetime health outcomes and healthcare costs.

- To explore the impact of different modes of supplementary care on all-cause mortality, disease-specific outcomes, and health service use rates and costs among people with major NCDs during the post-COVID-19 period (objective 3).

We will assess continuity of care and different modes of care including drug refill by proxy attendance, public private partnership programme and family medicine and specialty share care clinics (eg, cardiac). The Usual Provide Continuity Index (UPCI) will be used to measure continuity of care, which represents the proportion of attendance given by the most frequently visited clinic over the total number of attendances of asubject.[39 40] People with an UPCI of 0.8 or higher will be considered to have continuity of care. Meanwhile, those with any attendances at different modes of care during the COVID-19 period will be counted as an attendance.

For the short-term investigation, linear or logistic regression adjusted with subjects' baseline characteristics will be conducted to evaluate the association between different modes of care and changes in disease severity indicators (eg, HbA1c, BP and estimated glomerular filtration rate (eGFR)) from 2019 to 2021. For the long-term investigation, the index date will be defined as the first doctor consultation attendance in 2020. Cox regression will be adopted to assess risk of all-cause mortality and disease-specific outcomes associated with different modes of care. In presence of overdispersion in Poisson regression, healthcare cost associated with these modes of care will be determined by Poisson regression or negative binomial regression.[41]

All significance tests were two-tailed, and those with a p value less than 0.05 were considered statistically significant. The statistical analysis was executed in R, Stata or other suitable software.

Patient and public involvement

Patients or the public are not involved in developing plans for recruitment, design, conduct, report or dissemination of the study.

DISCUSSION

This study aims to evaluate the spill-over impact of the COVID-19 pandemic on people with major NCDs. As the pandemic continues, containment measures such as

lockdowns and social distancing have created new barriers for people with healthcare needs to access appropriate care. We have already observed some immediate and short-term indirect health effects around the world during the past 2 years of the pandemic. Moreover, it is becoming more apparent that long-term effects could be substantial in the coming years. Thus, understanding the long-term impact on health and health system will help to mitigate avoidable harm and healthcare costs. By using big data in the public healthcare system that covers the whole population, supplemented by surveys on private health service use, this study will provide more comprehensive information on the extent to which the pandemic has affected the outcomes and healthcare of populations with NCDs. Furthermore, by exploring the effectiveness (or the lack of it) of alternative and supplementary modes of care and continuity of care during the pandemic, it will inform us how accessibility and quality of care can be assured for people with NCDs in the presence of competing demands.

Findings from this study will provide insight for strengthening the adaptability of the health system against future pandemics. Contingency care plans can be adjusted according to the needs of specific group with NCDs, and reorganisation of services can include NCD care as part of territorial response and preparedness plans for future healthcare crisis. Particularly, the identification of the high-risk groups and how quality of care for people with NCDs could be maintained with minimal risk for nosocomial infections can inform healthcare policy on what services are truly essential and how they can be sustained. The public must be reminded of the importance of seeking timely care for illnesses. Additional attention may be directed to the most impacted group of people with NCDs to include alternative modes of care to provide guidelines and support for disease management and to collaborate with community partners to ensure continuation of services catered to the needs of people with NCDs.

Limitations of the study should be noted as well. First, there is potential for misclassification bias in electronic database using ICPC-2 and ICD-9-CM.[42] Nonetheless, guidelines for reporting diagnosis and standardised terms used by clinicians in daily practice in Hong Kong may lower the risk of misclassification bias.[43] Previous studies have shown that theses codes have a high coding accuracy in diagnosing myocardial infraction and stroke with positive predictive values of 85.4%–91.1%.[44] Second, we anticipate there will be missing data in the extracted dataset. Our previous studies found missing rates were no more than 20% in most variables, which could be handled by MICE.[45] Third, the HA data are limited to records within the HA public health system. However, over 80% of people with chronic diseases and complications are managed in the HA public healthcare system in Hong Kong due to 84%–100% of cost subsidy by the government.[23] In addition, the cross-sectional surveys can compensate for private health service use, providing supplementary information. Fourth, the cross-sectional surveys are based on participants' self-report, which may lead to potential information bias such as recall bias. Lastly, as participants will be directly recruited from clinics, outcomes should be interpreted carefully, considering they do not reflect on the general population.

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Acknowledgements The authors are most grateful to the head office, clinicians and staff in primary care and specialist outpatient clinics of the Hong Kong West Cluster, and the Statistics and Workforce Planning Department of the Hong Kong Hospital Authority, and the Department of Health for their support in data collection and extraction.

Contributors EYFW and CLKL are the coprincipal investigators of the study. CLKL, EYFW and JQ initially conceived the study. EYFW, CLKL, JQ, ILM and HMY contributed to the coordination of the study and drafted and revised the manuscript. EYTY, CSL, MSMI, SCWT, ICKW, KKL, MSFL, CSN, KAG, DVKC and WWKK reviewed the manuscript and provided edits for intellectual content. All authors approved the final version of the manuscript to be published.

Funding This work was supported by the Food and Health Bureau, the Government of HKSAR (project number COVID19F08).

Disclaimer No funding organisation had any role in the design and conduct of the study; collection, management, analysis and interpretation of the data; and preparation of the manuscript. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Consent obtained directly from patient(s)

Provenance and peer review Not commissioned; externally peer reviewed.

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REFERENCES

1 Centers for Disease Control and Prevention,, National Center for Health Statistics. Excess deaths associated with COVID-19. Available: https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm [Accessed 22 March 2022].
2 Zalla LC, Mulholland GE, Filiatreau LM, *et al*. Racial/Ethnic and age differences in the direct and indirect effects of the COVID-19 pandemic on us mortality. *Am J Public Health* 2022;112:154–64.
3 Organisation for Economic Co-operation and Development. *Health at a glance 2021: OECD indicators*. Paris: OECD publishing, 2022.
4 Shiels MS, Almeida JS, García-Closas M. Impact of population growth and aging on estimates of excess us deaths during the COVID-19 pandemic, March to August 2020. *Annals of Internal Medicine*;2020.
5 World Health Organization. Rapid assessment of service delivery for NCDS during the COVID-19 pandemic, 2020. Available: https://www-who-int.eproxy.lib.hku.hk/publications/m/item/rapid-assessment-of-service-delivery-for-ncds-during-the-covid-19-pandemic
6 World Health Organization. Second round of the National pulse survey on continuity of essential health services during the COVID-19 pandemic 2021.
7 Benjamin-Chung J, Abedin J, Berger D, *et al*. Spillover effects on health outcomes in low- and middle-income countries: a systematic review. *Int J Epidemiol* 2017;46:1251–76.
8 Lange SJ, Ritchey MD, Goodman AB, *et al*. Potential Indirect Effects of the COVID-19 Pandemic on Use of Emergency Departments for Acute Life-Threatening Conditions - United States, January-May 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:795–800.
9 Giamello JD, Abram S, Bernardi S, *et al*. The emergency department in the COVID-19 era. who are we missing? *Eur J Emerg Med* 2020;27:305–6.
10 Barten DG, Latten GHP, van Osch FHM. Reduced emergency department utilization during the early phase of the COVID-19 pandemic: viral fear or Lockdown effect? *Disaster Med Public Health Prep* 2020:1–4.
11 Franchini S, Spessot M, Landoni G, *et al*. Stranger months: how SARS-CoV-2, fear of contagion, and Lockdown measures impacted attendance and clinical activity during February and March 2020 at an urban emergency department in Milan. *Disaster Med Public Health Prep* 2021;15:1–10.
12 Christey G, Amey J, Campbell A, *et al*. Variation in volumes and characteristics of trauma patients admitted to a level one trauma centre during national level 4 lockdown for COVID-19 in New Zealand. *N Z Med J* 2020;133:81–8.
13 Hartnett KP, Kite-Powell A, DeVies J, *et al*. Impact of the COVID-19 Pandemic on Emergency Department Visits - United States, January 1, 2019-May 30, 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:699–704.
14 Ojetti V, Covino M, Brigida M, *et al*. Non-COVID diseases during the pandemic: where have all other emergencies gone? *Medicina* 2020;56. doi:10.3390/medicina56100512. [Epub ahead of print: 01 Oct 2020].
15 Feral-Pierssens A-L, Claret P-G, Chouihed T. Collateral damage of the COVID-19 outbreak: expression of concern. *Eur J Emerg Med* 2020;27:233–4.
16 Oikonomou E, Aznaouridis K, Barbetseas J, *et al*. Hospital attendance and admission trends for cardiac diseases during the COVID-19 outbreak and lockdown in Greece. *Public Health* 2020;187:115–9.
17 Marijon E, Karam N, Jost D, *et al*. Out-Of-Hospital cardiac arrest during the COVID-19 pandemic in Paris, France: a population-based, observational study. *Lancet Public Health* 2020;5:e437–43.
18 Perlini S, Canevari F, Cortesi S, *et al*. Emergency department and out-of-hospital emergency system (112-AREU 118) integrated response to coronavirus disease 2019 in a northern Italy centre. *Intern Emerg Med* 2020;15:825–33.
19 Worldometers.info. COVID-19 CORONAVIRUS PANDEMIC Dover, Delaware, USA2020 [updated 2020 Dec 8; cited 2020 Dec 8]. Available: https://www.worldometers.info/coronavirus/
20 Teo K-C, Leung WCY, Wong Y-K, *et al*. Delays in stroke onset to hospital arrival time during COVID-19. *Stroke* 2020;51:2228–31.
21 Lui DTW, Lee CH, Chow WS, *et al*. A territory-wide study on the impact of COVID-19 on diabetes-related acute care. *J Diabetes Investig* 2020;11:1303–6.
22 Lui TKL, Leung K, Guo C-G, *et al*. Impacts of the coronavirus 2019 pandemic on gastrointestinal endoscopy volume and diagnosis of gastric and colorectal cancers: a population-based study. *Gastroenterology* 2020;159:1164–6.
23 Food and Health Bureau The Government of the Hong Kong Special Administration Region. Report of the Steering Committee on review of hospital authority; 2015.
24 Sud A, Jones ME, Broggio J, *et al*. Collateral damage: the impact on outcomes from cancer surgery of the COVID-19 pandemic. *Ann Oncol* 2020;31:1065–74.
25 Hanna TP, King WD, Thibodeau S, *et al*. Mortality due to cancer treatment delay: systematic review and meta-analysis. *BMJ* 2020;371:m4087.
26 Wu J, McCann A, Katz J. *Deep Singh K. 412,000 missing deaths: tracking the true toll of the coronavirus outbreak*. The New York Times, 2020.
27 EYF W, Fung CSC, Jiao FF. Five-Year effectiveness of the multidisciplinary risk assessment and management Programme–Diabetes mellitus (RAMP-DM) on diabetes-related complications and health service uses—a population-based and propensity-matched cohort study 2018;41:49–59.
28 Chow S-C, Shao J, Wang H. Sample size calculations in clinical research: Chapman and hall/CRC 2017.
29 Fleiss JL, Levin B, Paik MC. Statistical methods for rates and proportions: john wiley & sons 2013.
30 Cohen J. Statistical power analysis for the behavioral sciences: Routledge 2013.
31 Jiao FF, Fung CSC, EYF W. Five-Year cost-effectiveness of the multidisciplinary risk assessment and management Programme–Diabetes mellitus (RAMP-DM) 2018;41:250–7.
32 Jiao F, EYF W, Fung CSC. Cost-Effectiveness of a primary care multidisciplinary risk assessment and management program for patients with diabetes mellitus (RAMP-DM) over lifetime 2019;63:259–69.
33 Lian J, McGhee SM, So C. Five-year cost-effectiveness of the patient Empowerment programme (PEP) for type 2 diabetes mellitus in primary care 2017;19:1312–6.
34 Surveillance and Epidemiology Branch Centre for Health Protection Department of Health. Report of population health survey 2014/15, 2017. Available: https://www.chp.gov.hk/files/pdf/dh_phs_2014_15_full_report_eng.pdf [Accessed on 31 May 2022].
35 Hong Kong Hospital Authority. Hospital authority ordinance (Chapter 113) revision to list of charges. Available: https://www.gld.gov.hk/egazette/pdf/20172124/egn201721243884.pdf [Accessed 30 May 2022].
36 Rubin DB. Multiple imputation for nonresponse in surveys: John Wiley & Sons 2004.
37 Bernal JL, Cummins S, AJljoe G. Interrupted time series regression for the evaluation of public health interventions: a tutorial. 2017;46:348–55.
38 Fine JP, RJJJotAsa G. A proportional hazards model for the subdistribution of a competing risk 1999;94:496–509.
39 Dearinger AT, Wilson JF, Griffith CH. The effect of physician continuity on diabetic outcomes in a resident continuity clinic 2008;23:937–41.
40 Lustman A, Comaneshter D, SJPcd V. Interpersonal continuity of care and type two diabetes 2016;10:165–70.
41 Consul P, Famoye FJCiS-T, Methods. Generalized poisson regression model 1992;21:89–109.
42 Birman-Deych E, Waterman AD, Yan Y. Accuracy of ICD-9-CM codes for identifying cardiovascular and stroke risk factors 2005;43:480–5.
43 Fung V, Cheung N, Szeto K. Hospital authority clinical vocabulary table: the past, the present, and the future 2004.

44 Wong AYS, Root A, Douglas IJ, *et al*. Cardiovascular outcomes associated with use of clarithromycin: population based study. *BMJ* 2016;352:h6926.

45 Dong W, Fong DYT, Yoon J-S, J-s Y, *et al*. Generative adversarial networks for imputing missing data for big data clinical research. *BMC Med Res Methodol* 2021;21:78.

Supplementary A. The definition of non-communicable diseases based on ICPC-2 and ICD-9-CM codes

Disease	ICPC-2	ICD-9-CM	Clinical parameter
Diabetes mellitus	T89, T90	250.x	Not applicable
Hypertension	K86, K87	401.x-405.x	Not applicable
Cardiovascular diseases	K74-78, K89-91	410.x-414.x, 428.x 429.79, 430.x-438.x,	Not applicable
Cancer	A79, B72-B74, D74-D77, F74, H75, K72, L71, N74, R84-R85, S77, T71, T73, U75-U77, W72, X75-X77, Y78, Y77, Y79, X81, W73, S79, R92, N76, L97, D78, B75	140.x-209.x, 230.x-239.x	Not applicable
Chronic kidney diseases	Not applicable	585.3x, 585.4x, 585.5x, 585.6x	eGFR<60
Chronic respiratory diseases	R79, R95, R96, R03, R04, R05	490.x-496.x	Not applicable

Supplementary B. The structure cost questionnaire for public and private health service utilization

Demographic information:

1. Sex	1.Male			2.Female	
2. What is your date of birth?	☐☐ d	☐☐ m	☐☐☐☐ year		
3. What is your place of birth?	1.Hong Kong	2.Guangdong Province	3.Other provinces of mainland China	4.Macao	5.Other countries / regions
4. What is your highest level of education attainment?	1.No school / pre-primary	2.Primary	3.Secondary	4.Post-secondary or above	
5. What is your marital status?	1.Single	2.Married	3.Separated or divorced	4.Widowed	5.Refuse to answer
6. What is your current employment status?	1.Employed (full-time)	2.Employed (part-time)	3.Employer/self-employed	4.Unemployed	
	5.Retired	6.Refuse to answer			
7. What is your average monthly income, including all sources?	1.Below $5,000	2. $5,000 - $9,999	3.$10,000- $19,999	4.$20,000- $29,999	
	5.$30,000- $39,999	6.$40,000 or above	7.Refuse to answer	8.Don't know	
8. Are you covered by any health insurance?	1.Individually-purchased private health insurance	2.Employer-provided private health insurance	3.No		
9. Are you receiving any financial subsidies from the government ?	1.Comprehensive Social Security Assistance (CSSA)	2.Disability Allowance (DA)	3.Elderly health care vouchers	4.Old Age Living Allowance (OALA)	
	5.Others (specify)	6.No			

Doctor-diagnosed chronic conditions:

10. Have you been diagnosed with any of the following chronic conditions?	1. Cancer	2. Stroke	3. Coronary Heart disease
	4. Asthma	5. Chronic obstructive pulmonary disease	6. High blood cholesterol
	7. Hypertriglyceridemia	8. Hypertension	9. Diabetes mellitus
	10. Kidney diseases	11. Liver disease	12. Musculoskeletal diseases
	13. Skin diseases	14. Thyroid disease	15. Stomach and intestinal diseases
	16. Respiratory disease (other than asthma and COPD)	17. Parkinson's disease	18. Epilepsy
	19. Anemia	20. Congenital blood diseases	21. Mental health illnesses. Specify:
	22. Immune diseases	23. Others (specify):	

Utilization of private health services:

11. Did you have any in-person private doctor consultation during 2020 (during COVID-19 outbreak) (western medicine / Chinese medicine)? *(If no, go to Q12)*	1. Yes 2. No		
a. How many visits?	1. General Practitioner visits	2. Specialist visits	3. Chinese Medicine visits
12. Did you have any in-person private allied health professional consultation during the whole year of 2020 (e.g., physiotherapists / occupational therapists / dietitians)? *(If no, go to Q13)*	1. Yes 2. No		
a. How many visits?	visits		
13. Did you have any private doctor teleconsultation during the whole year of 2020 (western medicine / Chinese medicine)? *Teleconsultation: the practice of medicine over a distance through telecommunication systems	1. Yes 2. No		
a. How many visits?	1. General Practitioner visits	2. Specialist visits	3. Chinese Medicine visits
14. Did you have teleconsultation with private allied health professionals during the whole year of 2020 (e.g. physiotherapists, occupational therapists, dietitians)? *Teleconsultation: the practice of medicine over a distance through telecommunication systems	1. Yes 2. No		

a. How many visits?	visits		
15. Have you taken any medication that was bought directly from the drug store during the whole year of 2020? *(If no, go to Q16)*	1.Yes 2. No		
16. Were you ever admitted to a private hospital during the whole year of 2020? *(If no, go to 17)*	1.Yes 2. No		
a. How many visits?	visits		
b. What was the length of each stay?	1. days	2. days	3. days
	4. days	5. days	6. days
c. In the year 2020, did you attend an accident & emergency department of a private hospital?	1. Yes, times	2. No	
17. Did you have any private medical tests during the whole year of 2020? *(If no, go to 18)*	1.Yes 2. No		
a. If yes, what type of medical tests? (exclude dental and vision examination) (choose all that apply)	1.General Health Screening packages		
	2. Cancer screening (mammogram/ breast ultrasound, Pap test, Prostate cancer screening, colonoscopy, etc)		
	3. Blood tests		
	4.Diagnostic imaging (DXA, X-ray, MRI, CT, etc)		
	5. Others (specify):		
b. How many times did you attend each type of medical tests during the whole year of 2020?	1.General Health Screening packages:	times	
	2. Cancer screening:	times	
	3. Blood tests:	times	
	4.Diagnostic imaging:	times	
	5. Others:	times	

Utilization of public health services:

18. Did you have any in-person public doctor consultation during 2020 (during COVID-19 outbreak) (western medicine / Chinese medicine)? *(If no, go to Q19)*	1.Yes 2. No		
a. How many visits?	1.General Practitioner	2.Specialist	3.Chinese Medicine
	visits	visits	visits
19. Did you have any in-person public allied health professional consultation during the whole year of 2020 (e.g., physiotherapists / occupational therapists / dietitians)? *(If no, go to Q20)*	1.Yes 2. No		
a. How many visits?	visits		

20. Did you have any public doctor teleconsultation during the whole year of 2020 (western medicine / Chinese medicine)? *(If no, go to Q21)* *Teleconsultation: the practice of medicine over a distance through telecommunication systems	1.Yes 2. No		
a. How many visits?	1.General Practitioner visits	2.Specialist visits	3.Chinese Medicine visits
21. Did you have teleconsultation with public allied health professionals during the whole year of 2020 (e.g. physiotherapists, occupational therapists, dietitians)? *(If no, go to Q22)* *Teleconsultation: the practice of medicine over a distance through telecommunication systems	1.Yes 2. No		
a. How many visits?	visits		
22. Were you ever admitted to a public hospital during the whole year of 2020? *(If no, go to 17)*	1.Yes 2. No		
a. How many visits?	visits		
b. What was the length of each stay?	1. days	2. days	3. days
	4. days	5. days	6. days
c. In the year 2020, did you attend an accident & emergency department of a public hospital?	1. Yes, times	2. No	

Supplementary C. Potential disease-specific indicators and complications of different subtype of NCD

Disease	Severity Indicators	Complications
Diabetes mellitus	Hemoglobin A1c	Cardiovascular disease End stage renal disease
Hypertension	Blood pressure	Cardiovascular disease End stage renal disease
Cardiovascular diseases	Troponins; Creatine kinase; Beta natriuretic peptide for heart failure; coronary angiogram for chronic IHD;	Recurrent event
Chronic kidney disease	Estimated glomerular filtration rate	End stage renal disease;
Chronic respiratory disease	FEV1/FEV	Non-COVID-19 related pneumonia (ICD-9-CM:460–466, 480–486); acute exacerbations (ICD-9-CM 491.21, 493.22, 493,92, 494.1)
Cancer	Stage of cancer	Stage progression