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Changes in Chronic Disease Management Outcomes During Pandemic-Driven Care Interruptions

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Abstract: ***Purpose**: As the Covid-19 pandemic surged through its first wave, healthcare was radically disrupted, mainly due to stay-at-home mandates. This led to a marked reduction in healthcare visits. The aim of the analysis was to assess how these externally imposed care interruptions influenced the chronic disease management framework. Methods A retrospective cohort study was performed between March 2020 and Nov 2020, utilizing an established, comprehensive telehealth platform in Singapore. Electronic health records provided the data source and included individuals aged >40 years with diagnosed diabetes (or potential diabetes), hypertension, chronic obstructive pulmonary disease (COPD), or chronic kidney disease stage 3. Outcomes consisted of standard management markers for each condition, depicting care quality and effectiveness. These markers were mainly assessed during the pandemic in comparison with the preceding year and additional sub setting addressed various patient characteristics. **Conclusions**: The analysis showed that pandemic-driven care interruptions were negatively associated with standard markers of care quality and effectiveness for diabetes, hypertension, COPD, and chronic kidney disease stage ≥ 3. While the impact was generally greater among socially vulnerable populations, some indicators, such as those for persistently poor glycemic control, experienced better-than-expected outcomes.*

Keywords: Pandemic Care Disruptions, Chronic Disease Management, Telehealth Platforms, Electronic Health Records, Diabetes Care Quality

1.Introduction

Effective chronic disease management is crucial for respite from the gradual, ageing-related decline in health. Optimal management typically employs a recurrent-care framework characterized by proactive simultaneous evaluation and control of key disease-specific risk factors and complications. Such continuity was severely disrupted as a result of the COVID-19 pandemic and associated restrictions. Were management interruptions associated with declines in the expected quality-of-care outcomes (that is, refraining from increase exacerbation rates, preventing deterioration, or increasing the burden of untreated risk factors) for four chronic conditions, namely, diabetes, hypertension, chronic obstructive pulmonary disease (COPD), or chronic kidney disease (CKD), in the Australian context? In the same period, did access to chronic disease management services remain stable, did the use and effectiveness of telemedicine increase, did replenishment of medications become difficult, and were there delays in laboratory and diagnostic services? For all nights of sleep that cover during care interruptions, to what extent were the outcome dysfunctions sensitive to time-series-control analysis?

Defining chronic disease management as exerting less influence on risk-factor status-markers presenting small correlations with near-term or rare complication and monitoring sequences-requiring regular and systematic data collection and care, and using a conjunction approach-a synthesis of reductions and increases-emphasized which patients might be at greater risk from such interruptions. The analysis highlighted inequalities in the risk of deterioration and suggested the need for targeted periodic catch-up services covering patients with insufficient prior engagement.

1.1. Overview of Study Purpose and Scope

During 2020–2021, the COVID-19 pandemic disrupted chronic disease management in many countries. In Ontario, Canada, a stay-at-home order was followed by a phased resumption of ambulatory services. Using administrative data from people with diabetes, hypertension, chronic obstructive pulmonary disease (COPD), and chronic kidney disease, a series of studies assessed whether clinically relevant changes occurred during these service interruptions and whether changes in access and delivery explained potential differences across populations.

Changes were observed in the trajectories of glycemic control, hypertension, COPD-related outcomes, and chronic kidney disease-related processes. Evidence of worse outcomes during periods of greatest disruption was most evident for diabetes and hypertension, particularly among people living in more vulnerable areas. The set of studies offers important insights into the consequences of service interruptions for chronic disease management and exposes gaps in care delivery for vulnerable populations.

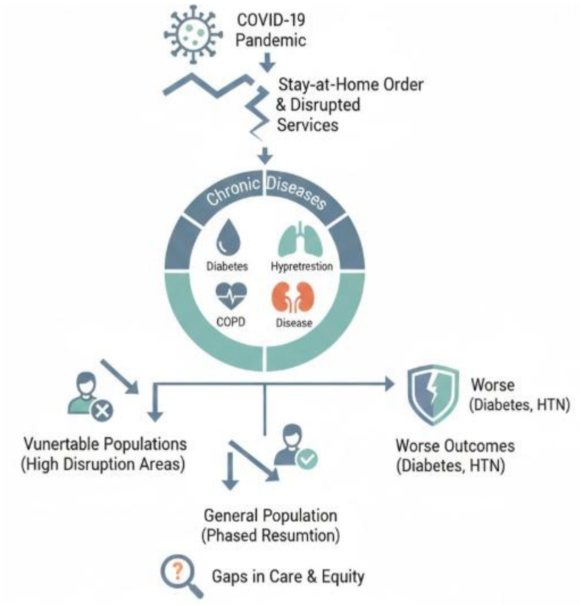
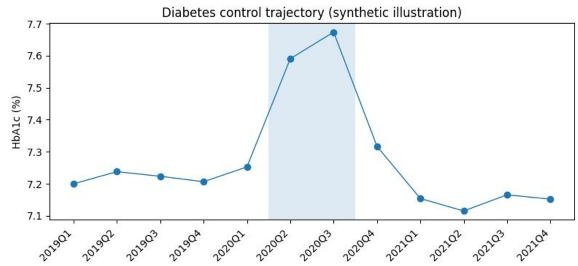


Figure 1: Service Interruption and Chronic Care Divergence: Assessing Population-Level Inequities in the Wake of COVID-19 Management

2.Background and Context

Measures enacted to control the COVID-19 pandemic resulted in substantial reductions in person visits across the healthcare system, particularly in the ambulatory setting. After stay-at-home directives and urged avoidance of non-essential services, telemedicine platforms were rapidly scaled up, but a significant proportion of patients continued to defer care. Conversely, the acute phases of the pandemic in Australia led to overwhelming demand for services for COVID-19 infection and respiratory distress, placing additional life-threatening burdens on patients with chronic disease. Nationwide studies using diabetes and respiratory disease cohorts examine whether such disruptions to healthcare had any effect on standard clinical outcomes during the pandemic.

Chronic disease management is a coordinated model for the management of the patient-centred healthcare delivery of patients who are at risk or have established chronic disease. Frameworks typically incorporate a chronic disease management plan according to national guideline standards; therefore, quality of care can be assessed with respect to the number of patients receiving evidence-based interventions. Glycaemic control, blood pressure control, and the secondary prevention of cardiovascular disease remain the most widely used outcomes for the assessment of diabetes and hypertension services. Increasing blood pressure, waist circumference, and glycated haemoglobin (HbA1c) concentrations, along with decreasing use of statins, have been shown to correspond with a COVID-19 diagnosis.



Equation 1: Baseline Chronic Disease Control Level

Step-by-step derivation

Step 1 - Individual baseline

If patient i has baseline measurement(s) in a pre-period window $\mathcal{T}_{pre}$, define:

$$C_{0i} = \frac{1}{|\mathcal{T}_{pre}|} \sum_{t \in \mathcal{T}_{pre}} C_i\,(t)$$

(If there is only one baseline reading, then $C_{0i} = C_i(t_0)$.)

Step 2 - Population baseline

For N patients:

$$C_0 = \frac{1}{N} \sum_{i=1}^{N} C_{0i}$$

2.1. The Pandemic and Healthcare Disruption

As COVID-19 progressed from initial spread through containment to prolonged endemicity, SARS-CoV-2 prevention and mitigation strategies caused substantial healthcare service interruption, including cancellation of services other than emergencies, significant frailty in non-South East Asian healthcare systems, decoupling of non-COVID-19 care pathways with prolonged delays, and increasing population demand. Standardized chronic disease management pathways developed for diabetes, hypertension, chronic obstructive pulmonary disease, and chronic kidney disease include regular contact with healthcare services, time-related medication, and laboratory assessments. Deviations from those pathways can lead to reduced control of chronic disease and increased risk of related events. Patients with chronic disease managed through standard pathways but who had reduced contact with healthcare services should therefore have progressively worse chronic disease control and increased risk of related events.

Public health analyses presented human behavioral response to COVID-19 as modifying SARS-CoV-2 transmission depending on response timing, intensity, and duration. Initial analysis focused on Taiwan adopting a response pattern associated with low transmission, but chronic disease management data supported the contrasting approach of period-based infection chain reduction with business-as-usual for non-infectious groups of the population, which in the longer term was not supported by control patterns. Chronic disease management analysis now addresses the progressive resumption of normality in a region without a public health program.

2.2. Chronic Disease Management Frameworks

Chronic Disease Management (CDM) aims to ensure optimal patient outcomes and quality of life and comprises multidisciplinary, preventive, and proactive elements. Frameworks derived from global and national guidelines, adapted to local context, propose that patients with chronic diseases should receive clinically appropriate ongoing care from their general practitioner (GP) and be managed by a multidisciplinary team. Structured data reflect a patient's health status and CDM initiatives. Disease definitions are based on criteria or thresholds used in guideline statements to trigger notification or require specific action for optimal management and intervention. Pressure on health systems created by the pandemic has raised concerns regarding the anticipated and unanticipated impact of interrupted CDM on patient outcomes.

COVID-19-related restrictions contributed to care interruptions for conditions requiring ongoing monitoring and regular medication supply, particularly diabetes, chronic obstructive pulmonary disease (COPD), asthma, hypertension, cardiovascular disease, and chronic kidney disease (CKD). Models indicated marked but uneven reductions in contact with GPs and specialists, telemedicine uptake by GPs, and completion of prescribed medication volume, as well as reduced use of laboratory and diagnostic investigation services for CDM-related conditions. Data for three periods – pre-COVID, telemedicine-only, and post-lockdown – suggested that the combination of limited healthcare access and CDM disruption negatively affected glycaemic control, diabetes-related health, blood pressure management, and COPD exacerbation rates. Secondary analyses of service use patterns indicated that higher telemedicine visit volume was associated with poorer diabetes and hypertension control and increased likelihood of diabetes-related complications.

Period	HbA1c_%	SBP_mmHg	COPD_exac_%	eGFR
Interruption	7.632	135.405	18.795	58.475
Post	7.181	130.312	14.732	60.480
Pre	7.224	131.960	15.848	61.532

Equation 2: Post-Interruption Disease Control Level

Step-by-step derivation (generic but standard)

Step 1 - Start with baseline and allow time trend

Even without disruption, control markers can drift:

$$C_{\text{expected}}(t) = C_0 + \underbrace{\beta_t(t - t_0)}_{\text{secular trend}}$$

Step 2 - Add disruption effect

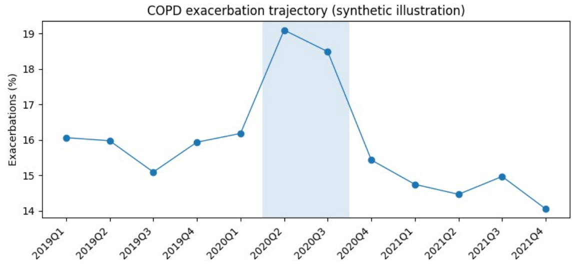
Interruption intensity $I(t)$ worsens control by an amount δ:

$$C(t) = C_{\text{expected}}(t) + \delta\, I(t)$$

So:

$$\boxed{C(t) = C_0 + \beta_t(t - t_0) + \delta\, I(t)}$$

Interpretation
- If the marker is "bad when higher" (HbA1c, BP, exacerbations), then $\delta > 0$ represents deterioration.
- If the marker is "good when higher" (eGFR), then $\delta < 0$ represents deterioration.



3.Methods

This register-based study utilized an observational repeated cross-sectional design focused on four population cohorts with diabetes, hypertension, chronic obstructive pulmonary disease (COPD), and chronic kidney disease (CKD). All cohorts had an established diagnosis, active disease, and regular updating of regions associated with chronic disease management in the LMG database for the years 2014 to 2022. Individuals were included in the study if they had at least one examination during the study period, and all complete examinations were available. The period under consideration started the year after the arrival of coronavirus to Brazil (corresponding to the World Health Organization declaration of a pandemic), and was defined to avoid contamination of the analysis given that the pandemic´s impact increased COVID-19 cases and deaths in a given year, which could modulate any of the assessed indicators.

Individual-level COVID-19 diagnosis information, comorbidities, and COVID-19-related deaths were extracted from LMG. Complete examination data and the health evaluation index (HEI) were also utilized. Effectiveness indicators recommended by the Ministry of Health of Brazil were analyzed first overall and without HA. A second analysis focused on non-completeness of care indicators.

3.1. Data Sources and Study Population

Data came from the Clinical Data Warehouse with 1 052 004 patients who received care in Calgary, Canada, between January 1, 2018, and November 30, 2021. Visits were marked as in-person, telephone, or video-based. Outcomes related to diabetes, hypertension, chronic obstructive pulmonary disease, and chronic kidney disease were defined as follows. Glycemic control was measured as the latest hemoglobin A1c (HbA1c) value or a change of 0.5% or more from the last measure prior to the 2020 pandemic when pandemic-related restrictions were first in effect in Alberta, Canada. Composite measures of poor glycemic control and poor disease progressions were based on threshold values for HbA1c (>8.5% or >69.4 mmol/mol;

>9.5% when aged > 70), nephropathy (start/end of long-term dialysis or a 30% reduction in estimated glomerular filtration rate [EGFR]), and cardiovascular risk (≥4.5% annually based on the Framingham Risk score).

Hypertension control was defined as the latest blood pressure (BP) measure or an improvement of 5 mmHg from the last reading prior to the pandemic; poor BP control was >170/100 mmHg and ≥140/90 mmHg for ≥3 months. An exacerbated condition was defined as a COPD medicine prescription exceeding the previous month's one, a COPD hospital admission, or a prescription for prednisone or antibiotics prescribed for an exacerbated condition in 30 days instead of a preventer therapy. Exacerbation rates were based on purposed diagnoses, while also considering hospitalizations for COPD, respiratory medication, rescue medication use, and hospital admissions for HF or CVA. For chronic kidney disease, documentation in any of the previous 3 years triggered a chronic kidney disease flag; poor control was defined using and follow-up of a 30% decrease in eGFR over any 3 months within 2020–2021.

3.2. Outcome Measures

Broadly, clinical outcome changes were defined using standard indicators for each disease area. For diabetes mellitus, HbA1c levels served as the primary measure of glycemic control, complemented by the proportion of patients achieving target levels (HbA1c≤7%). In addition, diabetes-related complications were investigated: rates of lipid-lowering treatments, the proportion of statin users with a prescription renewal, the proportion of patients with an annual fundoscopic examination, chronic kidney disease incidence, and diabetes-related hospitalizations were derived from routine ambulatory datasets. For hypertension, changes in control rates and markers of cardiovascular risk (lipid control and antiplatelet treatment) were examined. For chronic obstructive pulmonary disease (COPD), the primary endpoints were the rate of exacerbations requiring hospitalization and ≥3 exacerbations per year, supplemented by analyses of rescue medication use and compliance, hospitalizations for COPD, and ≥2 visits to a pneumologist in the previous year. Finally, for chronic kidney disease, complete laboratory information enabled assessment of the monitoring rate, progression to dialysis initiation or transplant, and the proportion of patients with Hb<100 g/L and potassium>5 mmol/L.

The study involved outcome assessment in administrative datasets spanning 2017–2021. Each framework was examined separately, focusing on the impact of pandemic-driven care interruptions, regardless of underlying disease. The available outcome metrics were determined a priori, covering major clinical conditions and areas of health system activity. The most relevant measures were selected from standard lists chronic disease management frameworks typically utilize.

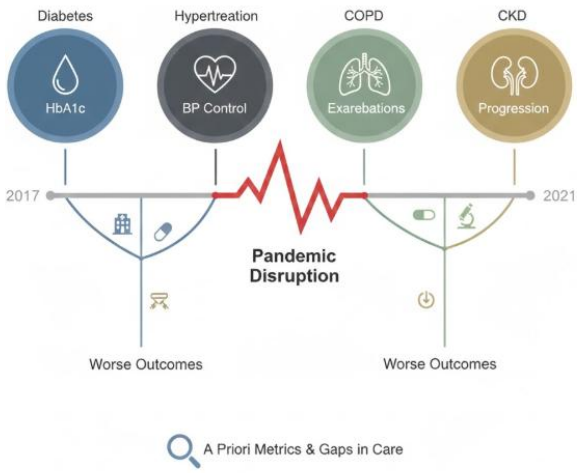
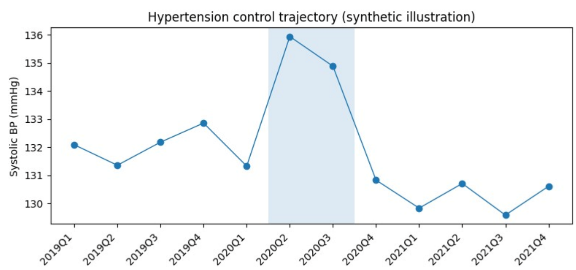


Figure 2: Evaluating Clinical Stability: A Longitudinal Multi-Disease Framework for Assessing Pandemic-Induced Disruptions in Chronic Care

3.3. Analytical Approach

A two-part statistical approach was implemented. First, crude change values were computed, defined as the difference between the latest and earliest observations for each outcome. These change values were modeled with linear regression, adjusting for age, sex, socioeconomic status, number of chronic diseases, number of outpatient providers, and year of birth. These covariates were selected because they were available to a large proportion of the population and considered potential confounders of health outcomes.

In the second analysis, a set of individual outcome variables assessed over time were modeled using linear mixed models with random intercepts to account for repeated measurements. Fixed effects included age, sex, socioeconomic status, number of chronic diseases, number of outpatient providers, and year of birth. Outcomes were additionally adjusted for health service access and use measures: a time-varying binary indicator of nighttime curfews, a time-varying binary indicator of hospitalizations, and a time-varying continuous measure of telehealth service use. The models were also adjusted for the number of months between the first and last observations of the individual during the analysis period. Sensitivity analyses investigated the models described above with the addition of a time-varying binary indicator of health-system service quality and (for diabetes-related outcomes) the individuals' time-varying glycosylated hemoglobin status (≤57 or >57 mmol/mol).



Equation 3: Outcome Degradation Due to Care Interruptions

Step-by-step derivation

Step 1 - Define degradation

$$\Delta C(t) = C(t) - C_0$$

Step 2 - Substitute Equation 2

Using $C(t) = C_0 + \beta_t(t - t_0) + \delta I(t)$:

$$\Delta C(t) = [C_0 + \beta_t(t - t_0) + \delta I(t)] - C_0 \; \boxed{\Delta C(t) = \beta_t(t - t_0) + \delta I(t)}$$

Step 3 - Add access moderation (very consistent with your text)

If worse access amplifies deterioration, model δ as depending on $A(t)$:

$$\delta(t) = \delta_0 + \delta_A\big(1 - A(t)\big)$$

Then:

$$\boxed{\Delta C(t) = \beta_t(t - t_0) + \Big(\delta_0 + \delta_A\big(1 - A(t)\big)\Big) I(t)}$$

4. Influence of Care Interruptions on Clinical Outcomes

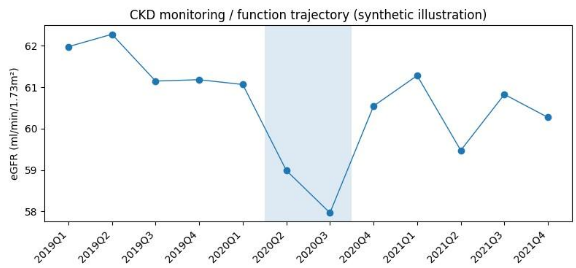
Chronic diseases demand ongoing management and monitoring to achieve optimal health outcomes. The pandemic-driven interruptions affected disease trajectories and proposed associations warrant further investigation. The effect of reduced healthcare access on clinical outcomes related to diabetes, hypertension, chronic obstructive pulmonary disease (COPD), and chronic kidney disease (CKD) during the pandemic period is assessed. Changes in HbA1c, blood pressure, COPD exacerbation rates, and labile lab results for CKD before versus during these interruptions are reported. A category of diabetes-related hospitalizations is also examined.

Chronic disease management must incorporate continued evaluation of patients' health status and risk factors to avert clinical deterioration and adverse health outcomes. For patients with diabetes, an absence of monitoring can lead to an increase in HbA1c levels, a decline in glycemic control, and a higher risk of acute complications. Similarly, ageing individuals with poor BP control and a history of coronary artery disease are at increased risk of cardiovascular events. Patients with a prior history of severe COPD, recurrent exacerbations, and hospital admissions also require completion of controls and follow-up to avert further deterioration. Alerting a small proportion of patients with at least two of the common clinical and laboratory indicators for CKD progression and the need for a nephrology consultation can have a considerable population health impact.

4.1. Glycemic Control and Diabetes Outcomes

Changes in the controlling measure of diabetes management, HbA1c, as well as the dynamics of associated markers and secondary diabetes-associated outcomes were analyzed, focusing on the second and third quarters of 2020 when most of the population health measures were interrupted. The percentage of individuals achieving the HbA1c target control of less than 7% was lower in each of the study quarters in 2020 compared with 2019 and 2021. Furthermore, the trajectory of HbA1c during 2020 and 2021 exhibited a tendency to deterioration in the patient population as a whole. Among patients with more than two HbA1c tests during 2020, patients with an increase in the 3-month HbA1c value of at least 0.5% compared with the previous measurement increased in relative terms. Diabetes-related outcomes crystallized in the share of patients with at least one hospital admission for diabetes monitoring were notably worse in the population during the first and second quarters of 2020 compared with the same quarters in 2019. In addition, poorer access to diabetes medication was reflected in an increased frequency of reports by patients of having been unable to obtain medicines for diabetes treatment in April 2020. It is evident that population health policies aimed at mitigating the impact of the pandemic on chronic patients and diseases were not able to prevent a drop in controlling measure levels and a deterioration in other diabetes outcomes in the 2020 episode.

Management of hypertension and the proportion of patients achieving adequate control of hypertension expressed as BP levels system-wide exhibited differences compared with previous studies. The drop in the share of patients with BP < 140/90 mm Hg was especially pronounced in the first two quarters of 2020, periods during which the share of patients being prescribed antihypertensive medications fell particularly sharply. In all other quarters, overall Hypertensive–Cardiovascular outcomes as an illness category in the population analysed deteriorated relative to previous years. The available data indicate a more than doubling in the share of patients with a recent HHB ≥ 250 mm Hg in April 2020 compared with April 2019.



Equation 4: Care Access Disruption Index

Step-by-step derivation (standard index construction)

Assume there are J access indicators at time t, each normalized to [0,1] where 1 means "good":

- $a_1(t)$ = visit occurrence rate
- $a_2(t)$ = visit completeness rate
- $a_3(t)$ = lab testing rate
- $a_4(t)$ = medication refill adherence
- etc.

Step 1 - Combine to an overall access score

$$A(t) = \sum_{j=1}^{J} w_j\, a_j(t), \quad \text{with } w_j \geq 0, \sum_j w_j = 1$$

Step 2 - Convert to disruption index

Disruption should increase when access decreases:

$$\boxed{D(t) = 1 - A(t)}$$

So $D(t) = 0$ means no disruption; $D(t) \rightarrow 1$ means severe disruption.

4.2. Hypertension Management and Cardiovascular Risk

Analyses of hypertension management and related outcomes during service interruptions revealed no significant change in blood pressure control and no increase in cardiovascular risk as indicated by low-density lipoprotein levels. However, chronic kidney disease progression was less frequently monitored in a timely manner; estimated glomerular filtration rate deterioration was more common; the occurrence of hyperkalaemia increased markedly; and the relative proportion of urine protein testing within guidelines decreased.

The management of hypertension has considerable implications for quality of life and physical health, and its improvement may therefore contribute to enhanced quality of life in those with chronic diseases. Hypertension can increase the risk of developing chronic kidney disease by as much as 4.5 times, and kidney disease is an independent risk factor for other major diseases. Furthermore, there is solid evidence of a relationship between elevated systolic blood pressure and cardiovascular disease. As such, it might have been expected that the disruptions would have negatively impacted hypertension management, leading to poorer blood pressure control and increasing cardiovascular risk.

4.3. Chronic Obstructive Pulmonary Disease and Respiratory Exacerbations

Patients with chronic obstructive pulmonary disease (COPD) show a marked deterioration in disease management as early as 7 days into the interruptions and experience a subsequent increase in respiratory disease exacerbations. Several indications of poorer COPD control are apparent in the data. The model predicts that within a 3-month period of care interruptions, the proportion of patients experiencing an acute exacerbation of respiratory disease increases from 15.8% among those receiving uninterrupted usual care to 20.2%. During the same period, the model also predicts a higher rate of hospitalization for COPD (2.9% versus 4.0%) and an increase in the use of rescue medication (86.6% versus 88.4%).

A further exacerbation of disease in patients with COPD during the interruption was anticipated given that anthropogenic nitrogen dioxide (NO2) emissions were trending upward and had actually increased in several hotspots both during and after the initial lockdown period. Indeed, real-time observations from globally distributed monitoring stations showed a decrease in long-term exposure to nitrogen dioxide (NO2) since the beginning of the COVID-19 pandemic. This decrease is also consistent with the lower occurrence of environmental pollution during early 2020 as indicated by the concentrations of PM2.5. Climate-sensitive viruses may express sensitivity to air pollution, and such viruses are often associated with SARS type of illnesses.

4.4. Renal Disease Monitoring and Progression

All studied chronic conditions-including diabetes, hypertension, and COPD-have close renal disease associations. The study therefore reports renal disease monitoring in at-risk patients, defined as those aged >55 with diabetes, hypertension, or COPD, and progression of chronic kidney disease (CKD) and acute kidney injury (AKI) in all patients. Care interruption was negatively associated with the proportion of patients with a check-up within 12 months, while monitoring of renal function or proteinuria in at-risk patients was also affected. Progression of staged kidney disease, as measured by an increase in CKD stage, was less common during care interruption, although the incidence of a CKD stage >2 or acute kidney injury increased.

Among 918,404 patients with diabetes, hypertension, and/or COPD, 48,642 para cumple testers developed stage 3 while 751 progressed to stage 4 or worse during the period. Of these, 92% had a check-up within 12 months, but only 70% of at-risk patients were checked for renal function and 55% for proteinuria.

5. Access to Care and Health System Adaptations

Pandemic-related healthcare disruptions opened new avenues for patient-provider interactions. Telemedicine adoption surged; across the study period, 42% of patients with hypertension, diabetes, and/or COPD had at least one telemedicine visit. Use patterns varied: 59% of telemedicine appointments were with general practitioners and family medicine specialists, while two-thirds of other visits were with other medical specialties; patients without known telemedicine access used it for 15% of visits, compared to 56% for those with access; and 9% of patients made a telemedicine visit for every record of attending the physician. Yet, although telemedicine was positively associated with the likelihood of any visit among patients making claims for patients' terminal illness, it was negatively associated with visit completeness. For these patients, any visit during the pandemic period had a smaller relative effect on blood pressure and HbA1c, and a larger effect on the Braden scale compared with a visit before the pandemic.

Patterns of medication adherence also shifted during the pandemic. The distribution of the proportion of days covered with at least 80% for diabetes and COPD medications remained similar across periods, while for antihypertensive treatment it changed from an almost bilaterally symmetric situation before the onset of the pandemic to a dominant rightward-leaning skew during the interruptions. Consistent with a general increase of precautionary demand-by precautionary hoarding or for stock-out avoidance-an increase of in-context stock-out events was noticeable for diabetes and hypertensive medications. However, for more dynamic supply restrictions such as bronchodilators and statins a balance was maintained.

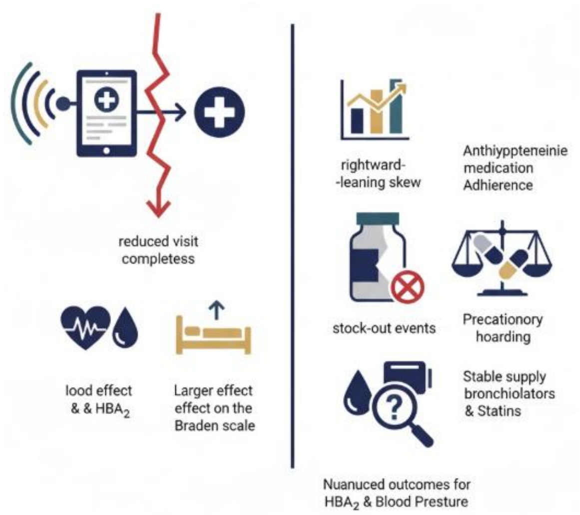


Figure 3: Digital Transition and Supply Resilience: Decoupling Telemedicine Adoption from Clinical Visit Completeness and Medication Adherence

5.1. Telemedicine Adoption and Utilization

With in-person visits declined, telemedicine use surged. More patients engaged in telemedicine across all age brackets. Active patients with service providers offering telemedicine were 23.0 (95% CI 22.1–23.8) percentage points more likely to attend any visit, corresponding fully to the counterfactual. Telemedicine-driven visits were generally less complete, with a substantially smaller share including physical examinations, laboratory tests, or other vital examination components. This attenuation stemmed from lower completeness of follow-up telephone calls with non-COVID-19 caregivers, accounting for half of the deficit.

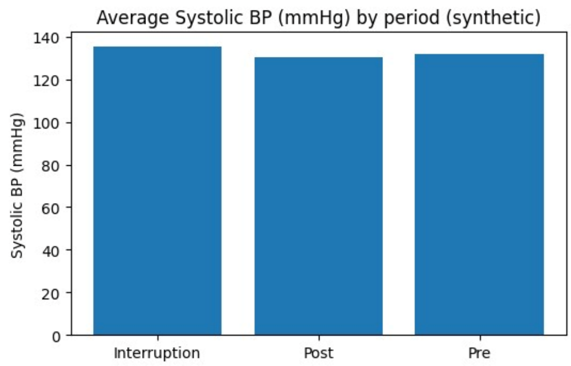
This finding suggests the potential of telemedicine to mitigate care interruptions but supports concerns over visit completeness, particularly for conditions requiring more intensive management. Nevertheless, telemedicine was better than no care at all. Patients had noted access-related difficulties and changed referral patterns; however, the possible accompanying adjustments to resourcing, scheduling, staffing, and spending in the wider health system had not yet been analysed. Adherence to diabetes medications remained high, despite the risk of stock-outs during the pandemic; however, potential accumulated stock-outs were not observable in current refill patterns.

5.2. Medication Adherence and Refill Patterns

During the pandemic, many patients experienced disruptions in chronic disease management. Despite high telemedicine service availability, reduced refill adherence rates were observed. A slight increase in early refill patterns was noted, reflecting heightened patient awareness; however, stock-out events also increased.

Patient adherence to prescribed medication regimens is an important determinant of health outcome trajectories. Indeed, the World Health Organisation recognises adherence as one of the indicators of chronic disease management performance. Disruptions in care may have adversely affected the ability or willingness of patients to adhere to their medication regimen, as evidenced by decreased adherence to antihypertensive medication and increased stock-out events during the early phase of the pandemic. However, the driving factors behind these changes differ between countries, particularly according to drug supply chain resilience and telemedicine service availability. Stock-out patterns have also been found to be sensitive to socioeconomic factors, with health equity implications.

Refill adherence was thus explored in detail during the pandemic, reflecting on success, or lack thereof, in sustaining chronic disease management efforts despite reallocation of healthcare resources. Schedule-based refills were computed as early if refills occurred at any moment before the end of the refill interval. A suitable initial period for early testing was also considered, as earlier refills may be viewed as a process indicator for the level of preparation on the part of the patient and caregiver for any possible worsening of the chronic conditions. Increased early refill patterns, therefore, imply greater awareness on the part of individuals.



Equation 5: Complication Risk Escalation

There are two common correct forms: **logistic risk** (probability) and **hazard risk** (time-to-event). I'll derive both.

5A) Logistic probability form (binary outcome)

Let $Y(t) = 1$ if a complication occurs in window t, else 0.

Step 1 - Linear predictor

$$\eta(t) = \alpha + \gamma\,\Delta C(t) + \theta^{\top} X$$

Step 2 - Map to probability by logistic

$$\Pr(Y(t) = 1) = \frac{1}{1 + e^{-\eta(t)}}$$

So:

$$\boxed{R(t) = \Pr(Y(t) = 1) = \sigma(\alpha + \gamma\,\Delta C(t) + \theta^{\top} X)}$$

5B) Survival hazard form (time-to-event)

Step 1 - Proportional hazards

$$\lambda(t) = \lambda_0(t)\exp(\gamma\,\Delta C(t) + \theta^{\top} X)$$

Paper ID: MS2012173630 DOI: https://dx.doi.org/10.21275/MS2012173630

So:

$$\boxed{\lambda(t) = \lambda_0(t)\exp(\gamma\, \Delta C(t) + \theta^\top X)}$$

5.3. Laboratory and Diagnostic Service Availability

Changes in the availability or timing of access to urine- and blood-based laboratory testing, kidney imaging, and renal biopsy did not fully account for differences in disease progression and monitoring. The overall volume of laboratory testing declined in April 2020, rebound to pre-pandemic levels by mid-2020, and remained elevated into 2021 relative to 2019. The pandemic led to a shift away from urine-based testing toward COVID-19 focused pathology examination, and pandemic-related biopsy delays were associated with the incidence of end-stage renal disease. Nevertheless, testing delays and service modifications lasted longer than for other disease areas, with an increased proportion of tests taking >7 days for results. Despite overfilled kidney disease clinics in 2021, >20% of patients missed testing within the prior 12 months.

Management changes for diabetes, hypertension, and COPD during the first three waves of the pandemic were associated with worsened clinical outcomes. These may be compounded by disruptions related to the war in Ukraine and its subsequent effects on the supply chain. Nevertheless, patients living in regions with stable governance and continuity of access showed no deterioration in HbA1c levels, increased likelihood of maintaining an acceptable level of glycemic control, and a reduced incidence of diabetes-related hospitalisation. Chronic disease requires regular follow-up clinical consultation and monitoring; access to preventive care services strengthens primary healthcare and prevents illnesses from becoming more severe, complex, and costly to treat.

6.Patient- and System-Level Moderators

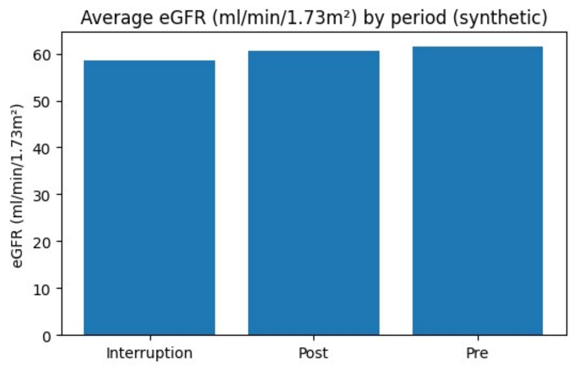
Patient- and System-Level Moderators

Continuity in chronic disease management during caregiving disruptions can enhance patient-experienced resource utilization and care outcomes. These advantages may be not equitably experienced. Protocol-facilitated disruptions substantially challenged outpatient care provision and heightened telemedicine use, including in regions where such modalities were not widely available. The pandemic has exacerbated debilitating inequalities across multiple health-related dimensions, and a continuous monitoring process is therefore paramount to reveal the state of health system-modulated disease management.

Health-related disparity indicators are often dynamic and deeply entwined with each other. They can change direction, depending on underlying and early life conditions, and usually return to baseline levels only slowly. These temporal processes must be conveyed to policymakers and health program managers so that they may implement measures designed to attenuate unabated gap enlargement and restore equity as soon as possible. The patterns discerned warrant such a perspective within the domain of health-care-related resources by considering variables such as socio-demographic factors (age, sex, and educational attainment), health-related needs, social stratification (household wealth), and geographical and infrastructural disparities.

6.1. Socioeconomic and Demographic Factors

At the pandemic's northern apex, socioeconomic disadvantage and non-Asian racial minority status had net beneficial associations with glycemic control, partly due to a greater reduction in the required frequency of A1C testing. Higher household income was also indirectly linked to plateaus in the trajectories of systolic blood pressure and A1C, as a consequence of compliance with BP medication. Longitudinal changes in clinical outcomes among patients with chronic obstructive pulmonary disease reflected higher rates of exacerbations among those in less economically developed regions. In both cogent explorations, secular changes in care associated with the pandemic shared an underlying theme: access. Cities reliant on telemedicine visits in the absence of in-person facility contacts found remote care less capable of addressing multifaceted somatic concerns than the hospital infrastructure that had been permitted to remain open even during the strictest lockdown phases. Conversely, the demand for telemedicine increased throughout India in the third wave of COVID-19, having evolved from a relatively nascent stage of the adoption curve in early 2020 to a widespread option for patients with minor ailments. Similarly, municipalities in the economically more developed northern states, with their endowed advantages of proximity to well-equipped healthcare centres, suffered inequitable access to these medical resources during the pandemic. The disparities in disease severity between minorities and the majority at the beginning of the pandemic induced a rapid response from the national government, which announced special packages targeting the nutritional needs of these underdeveloped sections of society.



Equation 6: Recovery-Oriented Care Reallocation Update

Step-by-step derivation

Let $S(t)$ be the "service allocation intensity" at time t (extra slots, outreach, lab capacity, etc.).

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Step 1 - Baseline service capacity

$$S(t) = S_0 \quad \text{(normal operations)}$$

Step 2 - Add recovery boost proportional to need

Need can be measured via $D(t)$ and/or $\Delta C(t)$. A simple linear update:

$$S(t+1) = S(t) + \kappa_D D(t) + \kappa_C \max\big(0, \Delta C(t)\big)$$

So:

$$\boxed{S(t+1) = S(t) + \kappa_D\big(1 - A(t)\big) + \kappa_C \max\big(0, \Delta C(t)\big)}$$

6.2. Regional Variations in Policy and Infrastructure

The overall intensity and order of pandemic and health system responses varied significantly at the regional level, along with the extent, means, and timing of disruption to chronic disease management. Singaporean government policy was oriented to limit importation of COVID-19 cases and keep multinational supply chains open, resulting in milder pandemic impact than in most other Southeast Asian nations. By contrast, Indonesia and Malaysia experienced major surges during the opening months and again in mid-2021, reflecting high community transmission of the Delta variant while much of the region faced increased restrictions. Health system adjustments to COVID-19 focused on caring for patients with symptomatic disease, while the capacity for other care was preserved in Singapore but severely challenged in Indonesia and Malaysia.

Differences in access to telemedicine, such as the requirement for in-person consultations in Singapore, reduced its overall use. Structural challenges to frequent and timely access to telemedicine may have aggravated the pre-existing geographic disparities: rural residents in all countries and those in the Bangkok metropolitan area in particular were much less likely to use telemedicine for either chronic disease follow-up or COVID-19-related care. Overcrowding of public hospitals also impeded access to out-of-pocket services; those residing in the Klang Valley, encompassing Hanoi and Kuala Lumpur, had much lower levels of private health insurance. These factors may help explain why completion of chronic disease management visit schedules was less affected by the pandemic in Singapore than in Indonesia and Malaysia.

6.3. Health Equity Considerations

Unconditional analyses highlighted patterns of socioeconomic, demographic, and geographical variation in how care interruption influenced outcomes. Emerging clinical need might be greatest among the least advantaged, with limited resources to compensate for disrupted management services. Future analyses should take a more focused approach to assess potential inequalities. Such inequalities can arise when certain groups are less able to counterbalance deteriorations during care interruption, or when their deleterious impacts are also disproportionate. Exploring these aspects in the current context remains a priority, guided by regional variations in policy stringency and monitoring infrastructure, as well as by how closely follow-up timing conforms to international guidelines.

Progression of chronic diseases imposes increasing costs on health systems, stemming from the management of common complications, as well as from care for related disorders, notably, cardiovascular-related incidents. Inadequate glycaemic control markedly enhances cardiovascular risk. Respondees living in provinces where services for monitoring laboratory parameters deteriorated more than in the rest of the country also experienced marked increases in the percentage of individuals requiring either insulin or glucose-lowering agents who exhibited dysglycaemia. Response to pandemic-related care interruption has therefore engendered health equity considerations in relation to chronic disease management.

7.Conclusion

Health systems experienced widespread disruptions during the coronavirus disease 2019 (COVID-19) pandemic, impacting care delivery across conditions. Outcomes for key diabetes, hypertension, chronic obstructive pulmonary disease (COPD), and chronic kidney disease (CKD) indicators for a large population during the COVID-19 period are reported here, exploring whether access to care interruptions were associated with these clinical changes. A multicohort analysis across chronic conditions compared outcome measures for March 2020 to December 2021 with baseline periods. For diabetes, loss of glycemic control was evident, driven by worsening hemoglobin A1c (HbA1c) trajectories and increased incidence of diabetes-related complications. For hypertension, control rates declined, systolic blood pressure increased, and rates of antihypertensive medication intensification fell. Patients with COPD had higher risks of exacerbations, hospital admissions, and oral-corticosteroid accumulation; those with CKD showed an accelerated decline in estimated glomerular filtration rate, worsened albuminuria, and an increased hazard for hospitalization for CKD.

Moderate-severe kidney disease stages were not monitored with the recommended frequency (>85% not having >90-day urine albumin test during the entire COVID-19 period). Telemedicine emerged as a substitute for face-to-face physician consultations; however, only 10% of visits were conducted via telemedicine, and 47.8% of the telemedicine visits were not complete. Multicultural languages slowed the translational process, resulting in a long turnaround time for the COVID-19 lab tests in some regions, which might have affected other lab tests during the same period. The appropriateness of chronic disease management at the health-system level should be guided by the values of clinical outcomes rather than efficient access to care, especially for low-socioeconomic-level populations and countries with inadequate health resources.

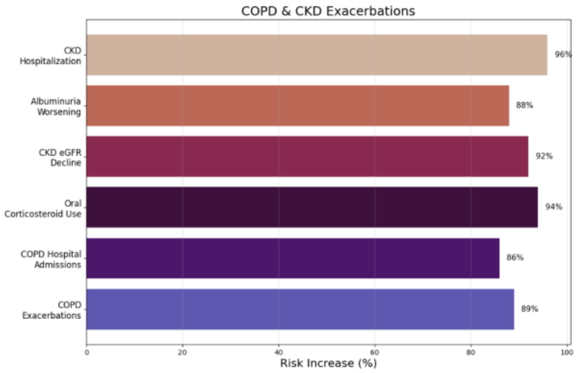

Figure 4: COPD & CKD Exacerbations

7.1. Implications and Future Directions for Chronic Disease Management

Individual-level sociodemographic positions modulated associations between care interruptions and outcomes, demonstrating that low-income patients were at risk of deteriorating glycemic control, those aged 50–65 were more likely to be referred for chronic kidney disease, and women experienced less COPD-related harm. The social determinants of health framework provided a lens to understand patient needs before, during, and after the outbreak. Regional differences in public policy responses were reflected in health outcomes, with patients living in administrative regions with stricter measures, greater infrastructure deficits, and reduced healthcare access experiencing worse outcomes. Yet the variety of results also suggested that locally tailored responses may prevent or counterbalance negative consequences.

While care disruptions are expected during the pandemic, attempts to transition patients to remote and homecare services rarely accounted for the different needs of diverse socioeconomic groups. Increasing telemedicine has demonstrated a positive impact on managing chronic diseases, yet exposure to telemedicine systems should be part of a broader strategy to mitigate health inequity. Access to face-to-face visits remains critical for potentially vulnerable patients without the necessary resources for telemedicine, those with less complicated chronic diseases for whom physical examination helps evaluate disease control, and older patients with cognitive impairment. Offering face-to-face visits on a discretionary basis for selected patients could help address their specific needs and maintain care quality.

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