Patterns, Volume *5*

Supplemental information

A latent transfer learning method for estimating hospital-specific post-acute healthcare demands following SARS-CoV-2 infection

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Supplemental Information

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Supplemental Experimental Procedure

A. Benchmarks

Traditionally, the estimation of the average treatment effect can be assessed by following the causal inference framework in a conventional single-site setting where only target samples were available. For simplicity, we let $i = 1, \ldots, n_0$ indicate subjects in the target hospital. In practical applications, the correct specification of an outcome model or a propensity score model (the model predicting the treatment assignment based on patient covariates) needs adequate background knowledge which is typically lacking. The Augmented Inverse Propensity Weighted (AIPW) estimator is a combination of two models, offering improved robustness. The AIPW estimator is doubly robust in the sense that when either the outcome model or the propensity score model is correctly specified, it produces a consistent estimator of average treatment effect[1]. Specifically, we consider a parametric model $g_c(a, x_i; \theta_{c,a})$ for the conditional expectation of outcome in each treatment group of c-th subpopulation. The probability of treatment assignment in the c-th subpopulation follows $P(A_i = 1|x_i) = e_c(x_i; \beta_c)$. $\hat{\theta}_{c,a}$ and $\hat{\beta}_c$ denote corresponding estimated parameters. Then, the AIPW estimator is defined as

$$\hat{\Delta}_c = \frac{1}{n_{0c}} \sum_{i=1}^{n_0} \left[g_c(1, x_i; \hat{\theta}_{c,1}) - g_c(0, x_i; \hat{\theta}_{c,0}) + \frac{A_i\{Y_i - g_c(1, x_i; \hat{\theta}_{c,1})\}}{e_c(x_i; \hat{\beta}_c)} - \frac{(1 - A_i)\{Y_i - g_c(0, x_i; \hat{\theta}_{c,0})\}}{1 - e_c(x_i; \hat{\beta}_c)} \right] I(C_i = c),$$

where $n_{0c} = \sum_{i=1}^{n_0} I(C_i = c)$ be the number of samples from c-th subpopulation. To construct a confidence interval for the AIPW estimator, either the sandwich estimator[2] or non-parametric bootstrap can be utilized for the sampling variance of $\hat{\Delta}_c$.

B. Definitions of study variables

Table S1: Variables used in estimating the subpopulation-specific impacts of COVID-19 on healthcare utility in each hospital of PEDSnet network through the Latent-TL pipeline.

Variable	Functional form	Values	Detail	Codes/references
Age (years)	Linear	NA	Based on records in the person domain.	Age is defined as the integer of (date – birth date)/365.25
Sex	Indicator	Male/Female	Based on records in the person domain.	NA
Race/Ethnicity	4 categories	Non-Hispanic White Non-Hispanic Black Hispanic Other/unknown	Based on records in the person domain.	NA
Obesity	Indicator	Yes/No	Based on records in the measurement domain.	NA

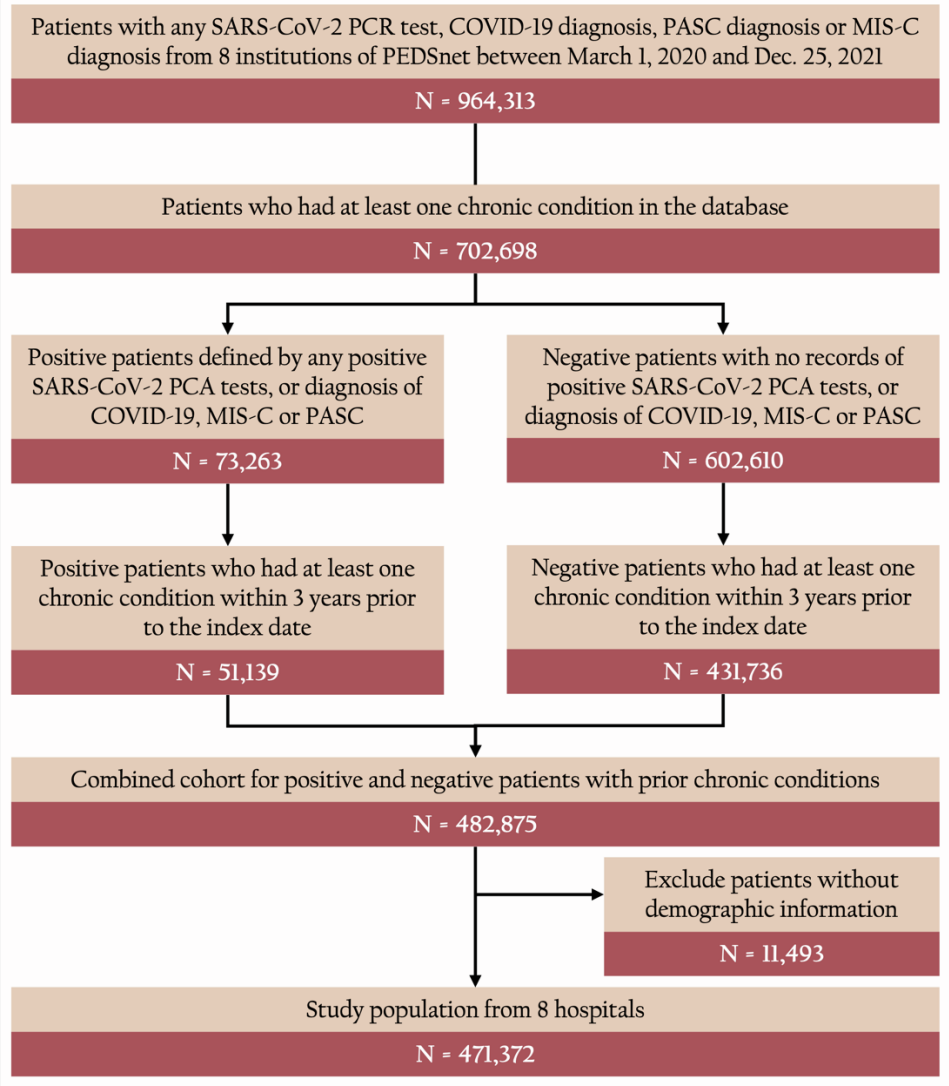
			If measured at age < 24*30.5 days, NHANES weight z score > 1.64 If measured at 24*30.5 < age <240*30.5, NHANES BMI z score > 1.64 If measured at age >= 240*30.5, BMI kg/m2 > 30	
Baseline visits per year (averaged during 3 years to 7 days prior to the entry)	Linear	NA	Based on the condition occurrence and visit occurrence domains.	NA
Diagnosis of each chronic condition cluster in 3 years to 7 days prior to the entry	Indicator	Yes/No	205 chronic condition clusters were defined based on the condition occurrence and visit occurrence domains. Chronic condition clusters with no observed events were removed in the analysis, which leads to 199 variables	Rao, S., Lee, G. M., Razzaghi, H., Lorman, V., Mejias, A., Pajor, N. M., ... & Forrest, C. B. (2022). Clinical features and burden of post-acute sequelae of SARS-CoV-2 infection in children and adolescents: an exploratory EHR-based cohort study from the RECOVER program. *medRxiv*, 2022-05.
Documented infection	Indicator	Yes/No	Based on the observation and visit occurrence domains. Defined as a polymerase-chain-reaction (PCR), serology, or antigen tests positive for COVID-19 in an inpatient or emergency department (ED) encounter, or diagnoses of COVID-19, post-acute sequelae of SARS-CoV-2 (PASC), or multisystem inflammatory syndrome in children (MIS-C) regardless of the presence of symptoms.	See https://github.com/PEDSnet/PASC/tree/main/observation_derivation_recover_ml_phenotype/specs for detailed codes.
Test location	3 categories	ED Inpatient Outpatient	Based on the observation and visit occurrence domains.	NA
Any inpatient visit 28-179 days after the entry	Indicator	Yes/No	Based on the condition occurrence and visit occurrence domains. Including inpatient hospital stay, emergency department admit to	NA

			inpatient hospital stay, and administrative visit.	
Any ED visit 28-179 days after the entry	Indicator	Yes/No	Based on the condition occurrence and visit occurrence domains.	NA

Note: All of the domains in the table above are based on the PEDSnet common data model (CDM). More details are available through this link: https://data-models-service.research.chop.edu.

C. Population selection workflow

Figure S1: Selection workflow of the study population based on PEDSnet COVID-19 Database Version 2024-03-14. Note that the population selection is based on a more recent version of the database than the one used in the original manuscript. Hence, the numbers may differ slightly due to updates in the COVID-19 data submitted by each hospital.



Note S1 Additional Population Statistics

Table S2. Distribution of pre-existing chronic conditions of patients < 21 years of age in the COVID-19 infection, no COVID-19 infection and overall cohorts.

Condition	COVID-19 Infection (N=49,430)	No COVID-19 Infection (N=382,735)	Overall (N=432,165)
Academic developmental disorder	2,205 (0.045%)	16,259 (0.042%)	18,464 (0.043%)
Acquired foot deformities	3,229 (0.065%)	25,030 (0.065%)	28,259 (0.065%)
Allergies	13,912 (0.281%)	89,489 (0.234%)	103,401 (0.239%)
Anxiety disorder	5,400 (0.109%)	35,444 (0.093%)	40,844 (0.095%)
Aplastic anemia	1,739 (0.035%)	11,808 (0.031%)	13,547 (0.031%)
Arrhythmias	1,093 (0.022%)	8,838 (0.023%)	9,931 (0.023%)
Asthma	9,158 (0.185%)	56,659 (0.148%)	65,817 (0.152%)
Attention deficit hyperactivity disorder	2,925 (0.059%)	18,462 (0.048%)	21,387 (0.049%)
Autism spectrum disorder	1,753 (0.035%)	15,731 (0.041%)	17,484 (0.040%)
Autoimmune thyroiditis	179 (0.004%)	1,337 (0.003%)	1,516 (0.004%)
Bipolar disorder	148 (0.003%)	1,085 (0.003%)	1,233 (0.003%)
Blindness and vision defects	2,588 (0.052%)	19,150 (0.050%)	21,738 (0.050%)
Cancer treatment	528 (0.011%)	3,292 (0.009%)	3,820 (0.009%)
Cannabis related disorders	306 (0.006%)	1,843 (0.005%)	2,149 (0.005%)
Cardiac and circulatory congenital anomalies	2,585 (0.052%)	24,353 (0.064%)	26,938 (0.062%)
Cardiomyopathy	197 (0.004%)	1,522 (0.004%)	1,719 (0.004%)
Cataract and other lens disorders	111 (0.002%)	1,127 (0.003%)	1,238 (0.003%)
Celiac disease	198 (0.004%)	1,681 (0.004%)	1,879 (0.004%)
Cerebral palsy	735 (0.015%)	5,945 (0.016%)	6,680 (0.015%)
Cerebrovascular disease	413 (0.008%)	3,370 (0.009%)	3,783 (0.009%)
Chromosomal abnormalities	1,123 (0.023%)	10,072 (0.026%)	11,195 (0.026%)
Chronic kidney disease	406 (0.008%)	2,813 (0.007%)	3,219 (0.007%)
Chronic obstructive pulmonary disease and bronchiectasis	193 (0.004%)	1,408 (0.004%)	1,601 (0.004%)
Cleft lip or palate	303 (0.006%)	3,679 (0.010%)	3,982 (0.009%)
Coagulation and hemorrhagic disorders	974 (0.020%)	6,320 (0.017%)	7,294 (0.017%)
Cognitive impairment	2,255 (0.046%)	16,885 (0.044%)	19,140 (0.044%)
Communication and motor disorders	4,451 (0.090%)	38,020 (0.099%)	42,471 (0.098%)
Conduct disorder	1,539 (0.031%)	10,327 (0.027%)	11,866 (0.027%)
Congenital malformations of eye, ear, face, neck	1,119 (0.023%)	10,546 (0.028%)	11,665 (0.027%)
Cornea and external disease	5,082 (0.103%)	35,255 (0.092%)	40,337 (0.093%)
Depressive disorders	321 (0.006%)	1,994 (0.005%)	2,315 (0.005%)
Developmental delay	1,791 (0.036%)	15,049 (0.039%)	16,840 (0.039%)
Diabetes mellitus type 1	543 (0.011%)	3,027 (0.008%)	3,570 (0.008%)

Diabetes mellitus type 2	324 (0.007%)	1,464 (0.004%)	1,788 (0.004%)
Digestive congenital anomalies	1,091 (0.022%)	10,526 (0.028%)	11,617 (0.027%)
Diseases of middle ear and mastoid except otitis media	2,454 (0.050%)	25,850 (0.068%)	28,304 (0.065%)
Diseases of white blood cells	1,300 (0.026%)	8,355 (0.022%)	9,655 (0.022%)
Disorders of jaw	136 (0.003%)	1,012 (0.003%)	1,148 (0.003%)
Disorders of lipid metabolism	1,314 (0.027%)	6,310 (0.016%)	7,624 (0.018%)
Dysautonomia	198 (0.004%)	1,693 (0.004%)	1,891 (0.004%)
Esophageal disorders	4,929 (0.100%)	38,172 (0.100%)	43,101 (0.100%)
Feeding and eating disorders	466 (0.009%)	3,662 (0.010%)	4,128 (0.010%)
Gender dysphoria	101 (0.002%)	1,346 (0.004%)	1,447 (0.003%)
Genitourinary congenital anomalies	2,049 (0.041%)	23,430 (0.061%)	25,479 (0.059%)
Glaucoma	123 (0.002%)	916 (0.002%)	1,039 (0.002%)
Hallucinations	166 (0.003%)	1,124 (0.003%)	1,290 (0.003%)
Hearing loss	2,632 (0.053%)	25,042 (0.065%)	27,674 (0.064%)
Heart failure	215 (0.004%)	1,721 (0.004%)	1,936 (0.004%)
Hypertension	1,080 (0.022%)	6,628 (0.017%)	7,708 (0.018%)
Hypothyroidism	526 (0.011%)	4,323 (0.011%)	4,849 (0.011%)
Immunity disorders	951 (0.019%)	5,930 (0.015%)	6,881 (0.016%)
Implant device or graft related encounter	5,625 (0.114%)	48,012 (0.125%)	53,637 (0.124%)
Intellectual disability	704 (0.014%)	5,141 (0.013%)	5,845 (0.014%)
Juvenile arthritis	184 (0.004%)	1,485 (0.004%)	1,669 (0.004%)
Leukemia	316 (0.006%)	1,561 (0.004%)	1,877 (0.004%)
Major depression	1,052 (0.021%)	6,385 (0.017%)	7,437 (0.017%)
Mental health treatment	4,094 (0.083%)	20,740 (0.054%)	24,834 (0.057%)
Minor depression	2,444 (0.049%)	14,876 (0.039%)	17,320 (0.040%)
Muscle disorders	3,259 (0.066%)	22,847 (0.060%)	26,106 (0.060%)
Musculoskeletal congenital conditions	3,823 (0.077%)	35,625 (0.093%)	39,448 (0.091%)
Myopathies	137 (0.003%)	1,504 (0.004%)	1,641 (0.004%)
Nephritis and nephrosis	174 (0.004%)	942 (0.002%)	1,116 (0.003%)
Nerve and nerve root disorders	269 (0.005%)	2,123 (0.006%)	2,392 (0.006%)
Nervous system cancers	162 (0.003%)	1,761 (0.005%)	1,923 (0.004%)
Nervous system congenital anomalies	1,046 (0.021%)	10,142 (0.026%)	11,188 (0.026%)
Neuro ophthalmology	794 (0.016%)	7,026 (0.018%)	7,820 (0.018%)
Neurocognitive disorders	193 (0.004%)	1,182 (0.003%)	1,375 (0.003%)
Neurodevelopmental disorders	2,656 (0.054%)	15,547 (0.041%)	18,203 (0.042%)
Nonmalignant breast conditions	539 (0.011%)	2,728 (0.007%)	3,267 (0.008%)
Nonrheumatic and unspecified valve disorders	537 (0.011%)	5,138 (0.013%)	5,675 (0.013%)
Obesity	7,284 (0.147%)	37,832 (0.099%)	45,116 (0.104%)
Obsessive compulsive and related disorders	374 (0.008%)	2,582 (0.007%)	2,956 (0.007%)
Oppositional defiant disorder	691 (0.014%)	4,239 (0.011%)	4,930 (0.011%)
Organ transplant status	368 (0.007%)	2,683 (0.007%)	3,051 (0.007%)
Other and ill defined heart disease	636 (0.013%)	5,316 (0.014%)	5,952 (0.014%)

Other nervous system disorders	1,143 (0.023%)	10,968 (0.029%)	12,111 (0.028%)
Other nervous system disorders	598 (0.012%)	4,940 (0.013%)	5,538 (0.013%)
Other specified and unspecified circulatory disease	474 (0.010%)	4,243 (0.011%)	4,717 (0.011%)
Other specified and unspecified congenital anomalies	1,923 (0.039%)	17,215 (0.045%)	19,138 (0.044%)
Other specified and unspecified diseases of bladder and urethra	516 (0.010%)	5,020 (0.013%)	5,536 (0.013%)
Other specified and unspecified diseases of kidney and ureters	1,152 (0.023%)	9,217 (0.024%)	10,369 (0.024%)
Other specified and unspecified disorders of stomach and duoden	489 (0.010%)	4,532 (0.012%)	5,021 (0.012%)
Other specified and unspecified endocrine disorders	1,833 (0.037%)	13,032 (0.034%)	14,865 (0.034%)
Other specified and unspecified gastrointestinal disorders	1,302 (0.026%)	11,303 (0.030%)	12,605 (0.029%)
Other specified and unspecified hematologic conditions	458 (0.009%)	2,455 (0.006%)	2,913 (0.007%)
Other specified and unspecified liver disease	483 (0.010%)	3,284 (0.009%)	3,767 (0.009%)
Other specified and unspecified mood disorders	335 (0.007%)	1,960 (0.005%)	2,295 (0.005%)
Other specified and unspecified nutritional and metabolic disorder	2,345 (0.047%)	15,535 (0.041%)	17,880 (0.041%)
Other specified bone disease and musculoskeletal deformities	2,175 (0.044%)	13,793 (0.036%)	15,968 (0.037%)
Other specified connective tissue disease	1,115 (0.023%)	6,789 (0.018%)	7,904 (0.018%)
Other specified diseases of veins and lymphatics	565 (0.011%)	3,904 (0.010%)	4,469 (0.010%)
Other specified female genital disorders	1,694 (0.034%)	9,415 (0.025%)	11,109 (0.026%)
Other specified joint disorders	2,257 (0.046%)	15,494 (0.040%)	17,751 (0.041%)
Pancreatic disorders excluding diabetes	216 (0.004%)	1,663 (0.004%)	1,879 (0.004%)
Paralysis other than cerebral palsy	355 (0.007%)	3,534 (0.009%)	3,889 (0.009%)
Peripheral and visceral vascular disease	162 (0.003%)	1,183 (0.003%)	1,345 (0.003%)
Pituitary disorders	378 (0.008%)	3,193 (0.008%)	3,571 (0.008%)
Polyneuropathies	226 (0.005%)	1,313 (0.003%)	1,539 (0.004%)
Psychological symptoms other	3,253 (0.066%)	20,686 (0.054%)	23,939 (0.055%)
Pulmonary heart disease	365 (0.007%)	3,020 (0.008%)	3,385 (0.008%)
Refractive error	4,188 (0.085%)	30,272 (0.079%)	34,460 (0.080%)
Regional enteritis and ulcerative colitis	280 (0.006%)	2,965 (0.008%)	3,245 (0.008%)
Respiratory congenital malformations	909 (0.018%)	7,503 (0.020%)	8,412 (0.019%)

Retinal and vitreous conditions	626 (0.013%)	4,876 (0.013%)	5,502 (0.013%)
Scoliosis	1,623 (0.033%)	12,327 (0.032%)	13,950 (0.032%)
Seizures and epilepsy	2,050 (0.041%)	19,030 (0.050%)	21,080 (0.049%)
Sickle cell trait anemia	528 (0.011%)	2,366 (0.006%)	2,894 (0.007%)
Sleep wake disorders	5,722 (0.116%)	47,911 (0.125%)	53,633 (0.124%)
Somatoform disorder	494 (0.010%)	3,261 (0.009%)	3,755 (0.009%)
Spondylopathies spondyloarthropathy	2,019 (0.041%)	13,591 (0.036%)	15,610 (0.036%)
Strabismus	1,820 (0.037%)	16,077 (0.042%)	17,897 (0.041%)
Systemic lupus and other connective tissue disorders	469 (0.009%)	2,763 (0.007%)	3,232 (0.007%)
Thyroid disorders	218 (0.004%)	1,574 (0.004%)	1,792 (0.004%)
Tic disorder	533 (0.011%)	4,166 (0.011%)	4,699 (0.011%)
Tobacco related disorders	156 (0.003%)	968 (0.003%)	1,124 (0.003%)
Trauma and stressor related disorders	1,891 (0.038%)	9,694 (0.025%)	11,585 (0.027%)
Vesicoureteral reflux	325 (0.007%)	2,827 (0.007%)	3,152 (0.007%)

Note S2 Characterization of Patient Subpopulations

In **Figure 3** of the manuscript, we use a heatmap to depict the identification of patient subpopulations derived from Multi-Site Latent Class Analysis (MLCA). This heatmap illustrates the incidence of chronic conditions across various subpopulations: each column represents a subpopulation, while rows correspond to distinct clusters of chronic conditions. While **Figure 3** emphasizes the top 50 most common chronic conditions, **Figure S2** offers a broader view, showcasing the incidence rates for all chronic conditions across each subpopulation.

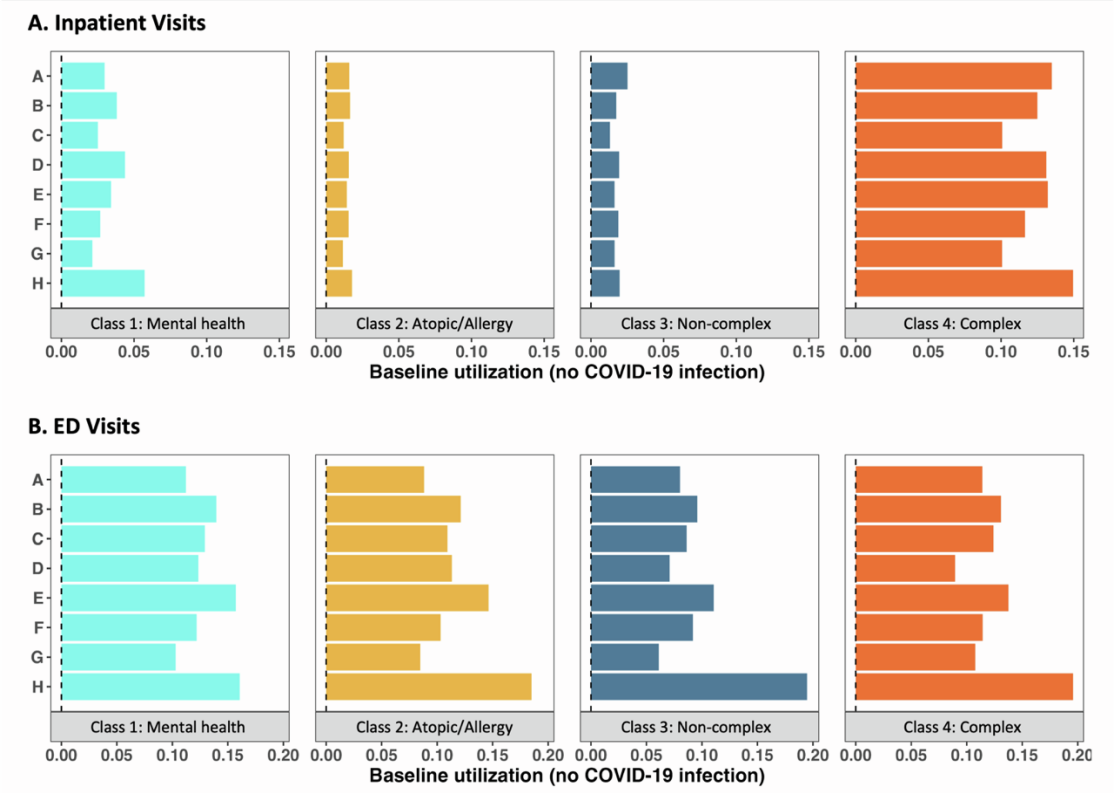
Figure S2. Chronic condition incidence across identified subpopulations via Multi-Site Latent Class Analysis (MLCA). This heatmap displays the prevalence of chronic conditions across four distinct subpopulations (or latent classes). Columns represent individual subpopulations, while rows detail the incidence rates of specific chronic condition clusters.


Implant, device or graft related encounter
Sleep–wake disorders
Communication and motor disorders
Esophageal disorders
Hearing loss
Refractive error
Acquired foot deformities
Musculoskeletal congenital conditions
Cardiac and circulatory congenital anomalies
Muscle disorders
Allergies
Obesity
Asthma
Anxiety disorder
Psychological symptoms, other
Attention deficit hyperactivity disorder
Neurodevelopmental disorders
Minor depression
Academic developmental disorder
Cognitive impairment
Seizures and epilepsy
Developmental delay
Blindness and vision defects
Other specified and unspecified nutritional and metabolic disor
Strabismus
Other specified and unspecified congenital anomalies
Aplastic anemia
Nervous system congenital anomalies
Other nervous system disorders (neither hereditary nor degenera
Chromosomal abnormalities
Diseases of middle ear and mastoid (except otitis media)
Genitourinary congenital anomalies
Cerebral palsy
Diseases of white blood cells
Hypertension
Neuro–ophthalmology
Coagulation and hemorrhagic disorders
Immunity disorders
Other specified and unspecified endocrine disorders
Other specified and unspecified gastrointestinal disorders
Scoliosis
Other specified joint disorders
Spondylopathies/spondyloarthropathy (including infective)
Other specified bone disease and musculoskeletal deformities
Congenital malformations of eye, ear, face, neck
Digestive congenital anomalies
Other and ill–defined heart disease
Nonrheumatic and unspecified valve disorders
Respiratory congenital malformations
Arrhythmias
Other specified and unspecified diseases of kidney and ureters
Mental health treatment
Cornea and external disease
Secondary malignancies
Osteoporosis
Cataract and other lens disorders
Heart disease, other
Opioid–related disorders
Nerve and nerve root disorders
Pancreatic disorders (excluding diabetes)
Dysautonomia
Chronic obstructive pulmonary disease and bronchiectasis
Myopathies
Systemic lupus and other connective tissue disorders
Nervous system cancers
Polyneuropathies
Cardiomyopathy
Other specified diseases of veins and lymphatics
Vesicoureteral reflux
Cleft lip or palate
Other specified connective tissue disease
Other specified and unspecified liver disease
Pituitary disorders
Other specified and unspecified hematologic conditions
Heart failure
Leukemia
Cannabis–related disorders
Obsessive–compulsive and related disorders
Other specified and unspecified mood disorders
Depressive disorders
Somatoform disorder
Tic disorder
Feeding and eating disorders
Diabetes mellitus, type 2
Tobacco–related disorders
Hallucinations
Bipolar disorder
Gender dysphoria
Nonmalignant breast conditions
Diabetes mellitus, type 1
Regional enteritis and ulcerative colitis
Sickle cell trait/anemia
Peripheral and visceral vascular disease
Nephritis and nephrosis
Posthrombotic syndrome and venous insufficiency/hypertension
Sarcoma
Non–hodgkin lymphoma
Hepatic failure
Bone cancer
Glaucoma
Endocrine system cancers
Thyroid disorders
Juvenile arthritis
Celiac disease
Disorders of jaw
Diabetes mellitus
Neurocognitive disorders
Autoimmune thyroiditis
Miscellaneous mental and behavioral disorders/conditions
Other specified substance–related disorders
Personality disorders
Psychotic disorder
Psoriasis
Cystic fibrosis
Cancer of other sites
Myositis
Conditions due to neoplasm or the treatment of neoplasm
Coronary atherosclerosis and other heart disease
Mediastinal disorders
Head and neck cancers
Gastrointestinal cancers
Urinary system cancers
Hypertension with complications and secondary hypertension
Malignant neoplasm, unspecified
Osteoarthritis
Sedative–related disorders
Menopausal disorders
Alcohol–related disorders
Fetal alcohol syndrome
Enuresis
Stimulant–related disorders
Schizophrenia
Amputation
Skin cancers
Respiratory cancers
Immune–mediated/reactive arthropathies
Inflammatory polyneuropathy
Female reproductive system cancers
Male reproductive system cancers
Pulmonary fibrosis
Antiphospholipid syndrome
Cardiac cancers
Schizoaffective disorder
Endometriosis
Encopresis
Catatonia
Paraphilia
Inhalant–related disorders
Osteomalacia
Temporal arteritis
Breast cancer
Other specified chronic arthropathy
Hyperplasia of prostate
Male infertility
Physical abuse
Sexual abuse
Emotional abuse
Varicose veins of lower extremity
Diverticulosis and diverticulitis
Parkinson's disease
Gout
Multiple myeloma
Neurogenic/neuropathic arthropathy
Malignant neuroendocrine tumors
Scleroderma
Multiple sclerosis
Hiv infection
Female infertility
Autoinflammatory syndromes
Vitiligo
Alopecia areata
Lung disease due to external agents
Myelodysplastic syndrome (mds)
Rheumatoid arthritis and related disease
Addison disease
Sequela of specified nervous system conditions
Arthritis
Spinal cord injury (sci)
Hodgkin lymphoma
Other specified female genital disorders
Disorders of lipid metabolism
Intellectual disability
Hypothyroidism
Other specified and unspecified disorders of stomach and duoden
Other specified and unspecified circulatory disease
Chronic kidney disease
Organ transplant status
Other nervous system disorders (often hereditary or degenerativ
Cancer treatment
Paralysis (other than cerebral palsy)
Retinal and vitreous conditions
Other specified and unspecified diseases of bladder and urethra
Pulmonary heart disease
Cerebrovascular disease
Major depression
Oppositional defiant disorder
Autism spectrum disorder
Conduct disorder
Trauma– and stressor–related disorders
0.5
0.4
0.3
0.2
0.1
0
Mental health
Atopic/Allergy
Non-complex
Complex

Note S3 Causal Estimation of Baseline Healthcare Utilizations

To further elucidate the connection between identified patient subpopulations and healthcare utilization trends, we projected baseline healthcare usage patterns under the theoretical premise where all patients remained unaffected by COVID-19. As delineated in **Figure S3**, the incidence of inpatient visits exhibited significant variation across the four discerned subpopulations, averaging across all hospitals at rates of 3.5%, 1.5%, 1.8%, and 12.4% for classes 1 through 4, respectively. On the other hand, the ED visit rates sustained a level of uniformity, spanning an average range of 9.9% to 13.1% across the quartet of subpopulations. Remarkably, Class 4, which encapsulates children grappling with complex chronic conditions, marked the peak frequency in baseline inpatient and ED visits during a period unaffected by the COVID-19 pandemic.

Figure S3. Hospital- and subpopulation-specific baseline healthcare utilization patterns. This figure illustrates the baseline patterns of inpatient (panel A) and ED (panel B) visits occurring between 28 and 179 days post-index date under the hypothetical scenario where all patients remained unaffected by SARS-CoV-2 infection.



Note S4 Negative Control Experiments

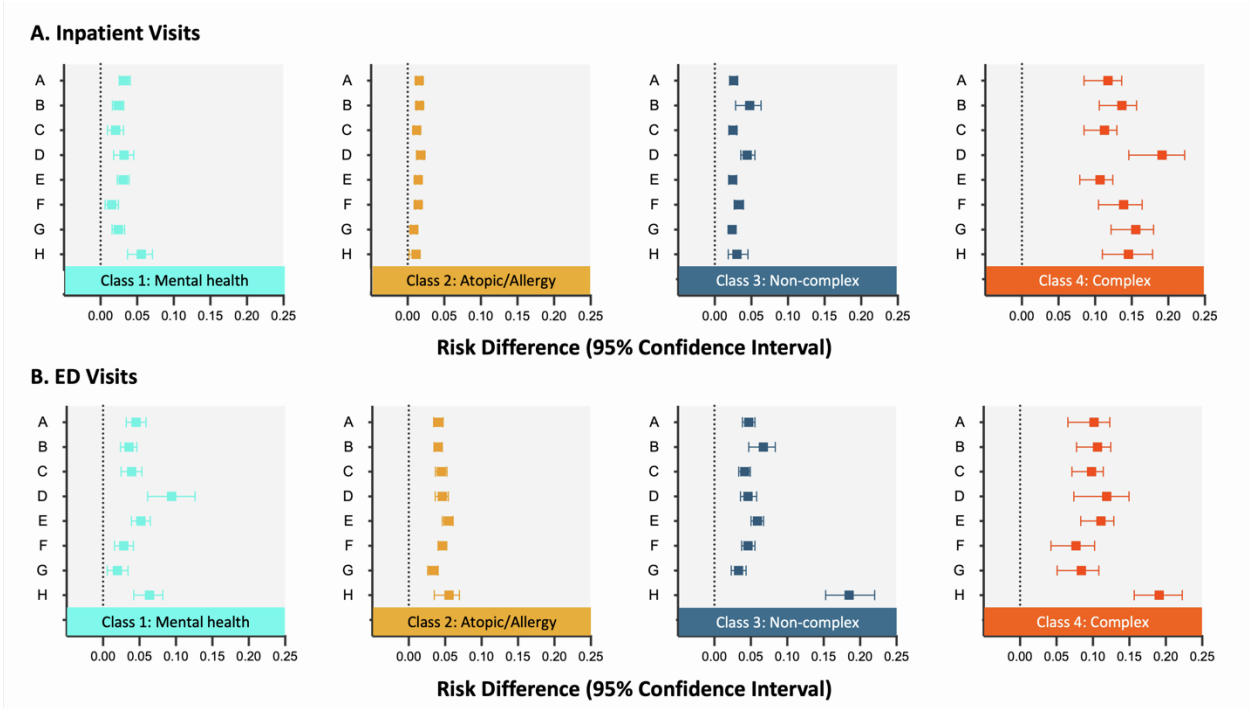
To mitigate potential biases originating from unmeasured confounders or systematic influences, we compiled a list of negative control outcomes. These outcomes, identified based on the ICD hierarchy[3], are presumed not to be caused by COVID-19 infection (for a comprehensive list please refer to **Table S3**). After excluding exceedingly rare events in our database, 33 negative control outcome variables were incorporated in the analysis. By applying the same analytical strategy to this collection of negative control outcomes, we establish a baseline or "null" distribution, aiding in the accurate identification and correction of potential biases in estimating our primary outcomes of interest. The recalibrated estimates showcased in **Figure S4** indicate a minimal degree of systematic error, alongside a slight increase in uncertainty, as characterized by the distribution estimated from the negative control outcomes.

Table S3. Negative control outcomes.

ICD-10-CM	Health conditions
H00-H06	Disorders of eyelid, lacrimal system and orbit
H10-H13	Disorders of conjunctiva
H15-H22	Disorders of sclera, cornea, iris and ciliary body
H25-H28	Disorders of lens
H30-H36	Disorders of choroid and retina
H40-H42	Glaucoma
H43-H45	Disorders of vitreous body and globe
H46-H48	Disorders of optic nerve and visual pathways
H49-H52	Disorders of ocular muscles, binocular movement, accommodation and refraction
H53-H54	Visual disturbances and blindness
H55-H59	Other disorders of eye and adnexa
H59-H59	Intraoperative and postprocedural complications and disorders of eye and adnexa, not elsewhere classified
Q00-Q07	Congenital malformations of the nervous system
Q10-Q18	Congenital malformations of eye, ear, face and neck
Q20-Q28	Congenital malformations of the circulatory system
Q38-Q45	Other congenital malformations of the digestive system
Q50-Q56	Congenital malformations of genital organs
Q60-Q64	Congenital malformations of the urinary system
Q65-Q79	Congenital malformations and deformations of the musculoskeletal system
Q80-Q89	Other congenital malformations
Q90-Q99	Chromosomal abnormalities, not elsewhere classified
S00-S09	Injuries to the head
S10-S19	Injuries to the neck
S20-S29	Injuries to the thorax
S30-S39	Injuries to the abdomen, lower back, lumbar spine and pelvis
S40-S49	Injuries to the shoulder and upper arm
S50-S59	Injuries to the elbow and forearm
S60-S69	Injuries to the wrist and hand
S70-S79	Injuries to the hip and thigh

S80-S89	Injuries to the knee and lower leg
S90-S99	Injuries to the ankle and foot
T00-T07	Injuries involving multiple body regions
T08-T14	Injuries to unspecified part of trunk, limb or body region
T15-T19	Effects of foreign body entering through natural orifice
T20-T32	Burns and corrosions
T33-T35	Frostbite
T36-T50	Poisoning by drugs, medicaments and biological substances
T51-T65	Toxic effects of substances chiefly nonmedicinal as to source
T66-T78	Other and unspecified effects of external causes
T79-T79	Certain early complications of trauma
T80-T88	Complications of surgical and medical care, not elsewhere classified
V00-V99	Transport accidents
W00-W99	Other external causes of accident injury I
X00-X59	Other external causes of accident injury II
X60-X84	Intentional self-harm
X85-X99	Assault I
Y00-Y09	Assault II
Y10-Y34	Event of undetermined intent
Y35-Y39	Legal intervention and operations of war
Y40-Y84	Complications of medical and surgical care
Y90-Y99	Supplementary factors related to causes of morbidity and mortality classified elsewhere

Figure S4: Hospital- and subpopulation-specific COVID-19 effects on inpatient (panel A) and ED (panel B) visits after calibrating negative control outcomes.


A. Inpatient Visits
A
B
C
D
E
F
G
H
Class 1: Mental health
Class 2: Atopic/Allergy
Class 3: Non-complex
Class 4: Complex
0.00 0.05 0.10 0.15 0.20 0.25
Risk Difference (95% Confidence Interval)
B. ED Visits
Class 1: Mental health
Class 2: Atopic/Allergy
Class 3: Non-complex
Class 4: Complex
0.00 0.05 0.10 0.15 0.20 0.25
Risk Difference (95% Confidence Interval)

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