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The Coronavirus Disease 2019 Pandemic is Associated with a Substantial Rise in Frequency and Severity of Presentation of Youth-Onset Type 2 Diabetes

Sheela N. Magge, MD, MSCE^{1,*}, Risa M. Wolf, MD^{1,*}, Laura Pyle, PhD², Elizabeth A. Brown, MPH¹, Valeria C. Benavides, MD, MPH³, Monica E. Bianco, MD⁴, Lily C. Chao, MD⁵, Anna Cymbaluk, MD⁶, Pinar Gumus Balickcioglu, MD⁷, Kelsee Halpin, MD, MPH⁸, Daniel S. Hsia, MD⁹, Lina Huerta-Saenz, MD¹⁰, Jane J. Kim, MD¹¹, Seema Kumar, MD¹², Lorraine E. Levitt Katz, MD¹³, Brynn E. Marks, MD, MSHPEd¹⁴, Anna Neyman, MD¹⁵, Katie L. O'Sullivan, MD¹⁶, Sabitha Sasidharan Pillai, MD¹⁷, Amy S. Shah, MD, MS¹⁸, Ashley H. Shoemaker, MD, MSCI¹⁹, Juwairriyyah A. W. Siddiqui, MD²⁰, Shylaja Srinivasan, MD²¹, Inas H. Thomas, MD²², Jeanie B. Tryggstad, MD²³, Maha F. Yousif, MD²⁴, and Megan M. Kelsey, MD, MS², on behalf of the COVID-19 and Type 2 Diabetes Consortium[†]

Objectives To evaluate the frequency and severity of new cases of youth-onset type 2 diabetes in the US during the first year of the pandemic compared with the mean of the previous 2 years.

Study design Multicenter (n = 24 centers), hospital-based, retrospective chart review. Youth aged ≤21 years with newly diagnosed type 2 diabetes between March 2018 and February 2021, body mass index ≥85th percentile, and negative pancreatic autoantibodies were included. Demographic and clinical data, including case numbers and frequency of metabolic decompensation, were compared between groups.

Results A total of 3113 youth (mean [SD] 14.4 [2.4] years, 50.5% female, 40.4% Hispanic, 32.7% Black, 14.5% non-Hispanic White) were assessed. New cases of type 2 diabetes increased by 77.2% in the year during the pandemic (n = 1463) compared with the mean of the previous 2 years, 2019 (n = 886) and 2018 (n = 765). The likelihood of presenting with metabolic decompensation and severe diabetic ketoacidosis also increased significantly during the pandemic.

Conclusions The burden of newly diagnosed youth-onset type 2 diabetes increased significantly during the coronavirus disease 2019 pandemic, resulting in enormous strain on pediatric diabetes health care providers, patients, and families. Whether the increase was caused by coronavirus disease 2019 infection, or just associated with environmental changes and stressors during the pandemic is unclear. Further studies are needed to determine whether this rise is limited to the US and whether it will persist over time. (*J Pediatr* 2022;251:51-9).

The incidence of youth-onset type 2 diabetes is rising worldwide. The SEARCH for Diabetes in Youth Study showed an increase in incidence of 5% per year in the US from 2002 to 2012,¹ such that prevalence nearly doubled between 2001 and 2017.² This has significant long-term implications, given observations from the Treatment Options for Type 2 Diabetes in Youth

From the ¹Division of Pediatric Endocrinology and Diabetes, Johns Hopkins Hospital/Johns Hopkins University School of Medicine, Baltimore, MD; ²Department of Pediatrics, University of Colorado Anschutz Medical Campus/Children's Hospital Colorado, Aurora, CO; ³Department of Pediatrics, Division of Endocrinology, University of Illinois, College of Medicine of Peoria/Children's Hospital of Illinois, Peoria, IL; ⁴Department of Pediatrics, Division of Pediatric Endocrinology, Northwestern University/Ann and Robert H Lurie Children's Hospital, Chicago, IL; ⁵Center for Endocrinology, Diabetes, and Metabolism, Children's Hospital Los Angeles, Los Angeles, CA; ⁶Department of Pediatric Diabetes and Endocrinology, Texas Children's Hospital/Baylor College of Medicine, Houston, TX; ⁷Division of Pediatric Endocrinology and Diabetes and Duke Molecular Physiology Institute, Duke University Medical Center, Durham, NC; ⁸Division of Endocrinology and Diabetes, University of Missouri-Kansas City School of Medicine, Children's Mercy Kansas City, Kansas City, MO; ⁹Our Lady of the Lake Children's Hospital/Pennington Biomedical Research Center, Baton Rouge, LA; ¹⁰Department of Pediatrics, Division of Pediatric Endocrinology and Diabetes, Penn State Health Children's Hospital/Penn State College of Medicine, Hershey, PA; ¹¹Department of Pediatrics, Division of Pediatric Endocrinology, University of California San Diego/Rady Children's Hospital San Diego, San Diego, CA; ¹²Department of Pediatrics, Division of Pediatric Endocrinology, Mayo Clinic, Rochester, MN; ¹³Division of Endocrinology and Diabetes, Children's Hospital of Philadelphia, Philadelphia, PA; ¹⁴Division of Endocrinology and Diabetes, Children's National Hospital, Washington DC; ¹⁵Department of Pediatrics, Indiana University School of Medicine/Riley Hospital for Children, Indianapolis, IN; ¹⁶Section of Adult & Pediatric Endocrinology, Diabetes & Metabolism, University of Chicago Medical Center, Chicago, IL; ¹⁷Division of Pediatric Endocrinology, Warren Alpert Medical School of Brown University/Hasbro Children's Hospital, Providence, RI; ¹⁸Division of Pediatric Endocrinology, Cincinnati Children's Hospital Medical Center & The University of Cincinnati, Cincinnati, OH; ¹⁹Department of Pediatrics, Division of Pediatric Endocrinology and Diabetes, Vanderbilt University Medical Center, Nashville, TN; ²⁰Department of Pediatrics, Columbia University Irving Medical Center, Harlem Hospital, New York, NY; ²¹Department of Pediatrics, Division of Endocrinology, University of California, San Francisco, San Francisco, CA; ²²Department of Pediatrics, Pediatric Endocrinology, University of Michigan, Ann Arbor, MI; ²³Department of Pediatrics, Section of Diabetes/Endocrinology, University of Oklahoma Health Sciences Center, Oklahoma City, OK; and ²⁴Department of Pediatrics, Pediatric Endocrinology, University of Texas Southwestern, Dallas, TX

*Contributed equally.

†List of additional members of the COVID-19 and Type 2 Diabetes Consortium is available at www.jpeds.com (Appendix).

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BMI	Body mass index
COVID-19	Coronavirus disease 2019
DKA	Diabetic ketoacidosis
EMR	Electronic medical record
HbA1c	Hemoglobin A1c
HHS	Hyperosmolar hyperglycemic syndrome
PPY	Prepandemic year
TODAY	Treatment Options for Type 2 Diabetes in Youth

(TODAY) study showing rapid β -cell failure³ and early onset of complications⁴ in least one-half of US youth with type 2 diabetes.

A recent study from the Centers for Disease Control and Prevention⁵ demonstrated an increased incidence of diabetes in youth following coronavirus disease 2019 (COVID-19) infection but did not differentiate diabetes type. Moreover, irrespective of concomitant COVID-19 infection, since the onset of the pandemic, pediatric endocrinologists have anecdotally experienced an unprecedented acute burden of newly diagnosed type 2 diabetes. Multicenter and/or population-based studies in the US and Europe suggest that the proportion of youth with type 1 diabetes presenting in diabetic ketoacidosis (DKA) rose early in the pandemic, but the impact on the overall incidence of type 1 diabetes is still unclear.⁶⁻¹⁰ Several US individual institutions showed an increase in both rates and severity of presentation of youth-onset type 2 diabetes during the pandemic.¹¹⁻¹⁵ However, multicenter/population-based data regarding effects of the COVID-19 pandemic on youth-onset type 2 diabetes have not yet been published.

This study was designed to compile retrospective data from electronic medical records (EMRs) from institutions across the US to assess the national impact of the COVID-19 pandemic on rates of youth-onset type 2 diabetes. Specifically, the aims were to compare the total number of new cases of youth-onset type 2 diabetes and the proportion of those youth presenting with metabolic decompensation (DKA and/or hyperosmolar hyperglycemic syndrome [HHS]) from March 2020 to February 2021 to the previous 2 years.

Methods

This retrospective, multicenter study examined trends in youth-onset type 2 diabetes diagnosis and incidence of metabolic decompensation at presentation during the first year of the COVID-19 pandemic (March 1, 2020, to February 28, 2021) compared with the previous 2 years (March 1, 2018, to February 29, 2020). This collaborative effort was organized by the Children's Hospital Colorado/University of Colorado School of Medicine and the Johns Hopkins Hospital/Johns Hopkins University School of Medicine, with 24 contributing diabetes clinics in the US ([Appendix](#)). Institutional review board approval was obtained by each contributing site, with a waiver of consent. Deidentified data were submitted to the coordinating center.

Patients ≤ 21 years old diagnosed with type 2 diabetes from March 1, 2018, to March 1, 2021, were included. Diagnosis of type 2 diabetes, in accordance with American Diabetes Association guidelines, required ≥ 2 negative diabetes-associated antibodies (glutamic acid decarboxylase-65, insulin antibodies, zinc transporter 8, and/or islet antibodies [islet antigen-2 or islet cell antibodies]), and no positive antibodies.¹⁶ Medication-induced diabetes, prediabetes, post-transplant diabetes, and body mass index (BMI) < 85 percentile were exclusionary. Patients were included if BMI ≥ 85 percentile was confirmed before onset of type 2 diabetes,

but acute weight loss resulted in BMI < 85 percentile at diagnosis. Inclusion criteria were designed to ensure participants had type 2 diabetes while being kept broad enough to ensure generalizability and reduce bias. Eligibility was adjudicated at each site based on these criteria. Of note, history of overweight/obesity was confirmed in 112 participants who do not have BMI at diagnosis due to missing height.

EMR-extracted data included diabetes-related clinical variables, sex, race/ethnicity, insurance type, age at diagnosis, BMI, hemoglobin A1c (HbA1c), and initial random blood sugar at diagnosis; for those with metabolic decompensation (DKA or HHS, or mixed DKA/HHS) at presentation, initial pH, bicarbonate, and serum osmolality were recorded. At 23 of 24 institutions, race and ethnicity were determined by 2 separate questions; in addition to these self-report questions, the University of Columbia uses Spanish language to help determine Hispanic/LatinX ethnicity if a family reports "other or unknown." Data extraction from EMR allowed for options of "other" and "unknown" for race, and thus some of these data are incomplete. Laboratory values reported as either above or below the limit of detection were set to the limit of detection. DKA was defined as either pH < 7.3 or bicarbonate ≤ 1.5 . DKA severity was categorized using the International Society for Pediatric and Adolescent Diabetes 2018 guidelines: mild DKA = pH 7.2-7.29 and/or bicarbonate 11-15 mmol/L, moderate DKA = pH 7.1-7.19 and/or bicarbonate 6-10 mmol/L, and severe DKA = pH < 7.1 and/or bicarbonate ≤ 5 mmol/L.¹⁷ HHS was defined as serum osmolality ≥ 330 mOsm/kg and serum glucose > 600 mg/dL. If data regarding pH or osmolality were missing, it was presumed that they did not present in DKA or HHS, respectively.

The primary outcome was the absolute case number of new-onset type 2 diabetes diagnosed in the first year of the COVID-19 pandemic, compared with the mean of the previous 2 years. The secondary outcome was the percentage of these patients presenting with metabolic decompensation (DKA, HHS, or mixed DKA/HHS) compared with the previous 2 years.

Statistical Analyses

Descriptive statistics reported include mean \pm SD for normally distributed continuous variables, median (25th, 75th percentile) for skewed continuous variables, and frequency and percentage for categorical variables. Groups were compared using either a *t*-test or ANOVA for normally distributed continuous variables, the Kruskal-Wallis test for non-normally distributed variables, and the χ^2 test for categorical variables.

A negative binomial time series model was used to model the count of youth-onset type 2 diabetes diagnoses per month. A background linear trend of 5% increase per year was assumed. Seasonality was assessed by allowing the number of diagnoses in a particular month to depend on the number in the previous month, and the number 12 months previously. A test of intervention was performed to determine whether the onset of the pandemic in March 1, 2020, had a significant effect on the count of diagnoses.^{18,19}

Table I. Demographic, anthropometric, and clinical characteristics of study participants

Characteristics	PPY 18-19	PPY 19-20	Pandemic	P value
Total new-onset type 2 diabetes, No.	765	886	1463	.005
Region, No. (%)				
Midwest	201 (26.3)	214 (24.2)	342 (23.4)	.114
Northeast	64 (8.4)	93 (10.5)	168 (11.5)	
South	265 (34.7)	277 (31.3)	458 (31.3)	
West	234 (30.6)	302 (34.1)	495 (33.8)	
Age at diagnosis, y, mean (SD) n = 22 missing	14.3 (2.3)	14.5 (2.4)	14.4 (2.3)	.226
Race/ethnicity, No. (%)				
Asian	20 (2.6)	24 (2.7)	40 (2.7)	.004
Black	231 (30.2)	267 (30.1)	519 (35.5)	
Hispanic	323 (42.3)	356 (40.2)	577 (39.4)	
White	121 (15.8)	143 (16.1)	187 (12.8)	
Other	49 (6.4)	45 (5.1)	88 (6.0)	
Unknown	20 (2.6)	51 (5.8)	52 (3.6)	
Sex, No. (%)				
Female	421 (55.1)	488 (55.1)	663 (45.3)	<.001
Male	343 (44.9)	398 (44.9)	800 (54.7)	
Insurance, No. (%)				
Private	182 (23.8)	207 (23.4)	305 (20.8)	.009
Public	556 (72.8)	647 (73.0)	1110 (75.9)	
Other	4 (0.5)	9 (1.0)	5 (0.3)	
Uninsured	20 (2.6)	22 (2.5)	27 (1.8)	
Unknown	2 (0.3)	1 (0.1)	16 (1.1)	
Location at diagnosis, No. (%)				
Inpatient	329 (43.1)	382 (43.1)	836 (57.1)	<.001
Outpatient	434 (56.8)	502 (56.7)	626 (42.8)	
Unknown	1 (0.1)	2 (0.2)	1 (0.1)	
COVID-19 at diagnosis, No. (%), n = 266 missing				
No	529 (82.4)	625 (82.3)	954 (66.0)	<.001
Unknown	113 (17.6)	133 (17.5)	456 (31.5)	
Yes	0 (0.0)	0 (0.0)	36 (2.5)	
BMI, kg/m ² , median [IQR] n = 112 missing	34.6 [29.6, 39.2]	34.3 [30.0, 39.3]	35.1 [30.9, 40.9]	.001
BMI % of 95th percentile, mean [SD]	133.88 (31.11)	132.41 (30.17)	137.04 (30.09)	.001
HbA1c, %, median [IQR] n = 14 missing	9.3 [7.3, 11.9]	9.7 [7.1, 12.1]	10.4 [7.9, 12.4]	<.001
Serum glucose (random), mg/dL, (median [IQR])	241 [142, 360]	246 [146, 361]	286 [171, 414]	<.001
pH, median [IQR],* n = 1837 missing	7.37 [7.30, 7.40] n = 261	7.36 [7.31, 7.39] n = 320	7.34 [7.21, 7.39] n = 695	<.001
Bicarbonate, mmol/L, median [IQR]* n = 1530 missing	23.0 [20.0, 26.0] n = 355	24.0 [19.0, 26.0] n = 401	21.0 [12.0, 25.0] n = 827	<.001
Serum osmolality, mOsm/kg, median [IQR]* n = 2657 missing	298.0 [292.0, 307.0] n = 122	297.0 [293.0, 304.5] n = 87	306.0 [293.0, 333.5] n = 247	.002
Diabetic ketoacidosis, No. (%)	70 (9.2)	79 (8.9)	304 (20.8)	<.001
Hyperglycemic hyperosmolar syndrome, No. (%)	7 (0.9)	6 (0.7)	56 (3.8)	<.001
Metabolic decompensation, No. (%)	72 (9.4)	80 (9.0)	307 (21.0)	<.001
DKA severity (%)				
Mild	25 (35.7)	33 (41.8)	121 (39.8)	.35
Moderate	30 (42.9)	25 (31.6)	93 (30.6)	
Severe	15 (21.4)	21 (26.6)	90 (29.6)	

SI conversion factors: To convert HbA1c to mmol/mol, multiply by 0.01, to convert serum osmolality to mmol/kg, multiply by 1.

*Data only included for subset of patients with data available.

The year from March 1, 2018, to February 28, 2019, is referred to as prepandemic year 18-19 (PPY18-19), from March 1, 2019, to February 29, 2020, as prepandemic year 19-20 (PPY19-20), and from March 1, 2020, to February 28, 2021, as the pandemic year.

Results

A total of 3459 patients with new-onset type 2 diabetes were identified from 24 centers across the US. Of these, 312 were excluded due to inadequate antibody data, 32 were excluded due to BMI <85 percentile, 1 was excluded due to suspicion for monogenic diabetes, and 1 was excluded due to young age, atypical of type 2 diabetes. Thus, the final analysis

included 3113 participants (Table I). The average number of new diagnoses per year in the 2 prepandemic years was 825, compared with 1463 diagnosed during the first pandemic year, an increase of 77.3% (Figure 1). The increase in new presentation was seen across almost all sites (Table II; available at www.jpeds.com). The largest contributing site reported 426 new cases (13.7% of the total sample). The South and West regions were over-represented, particularly compared with the Northeast (Table I, $P = .11$). The mean age at presentation did not change over the 3-year period.

Because of an apparent peak of diagnoses in August, a covariate corresponding to August vs other months was tested but was not significant. Thus, the final model did not include

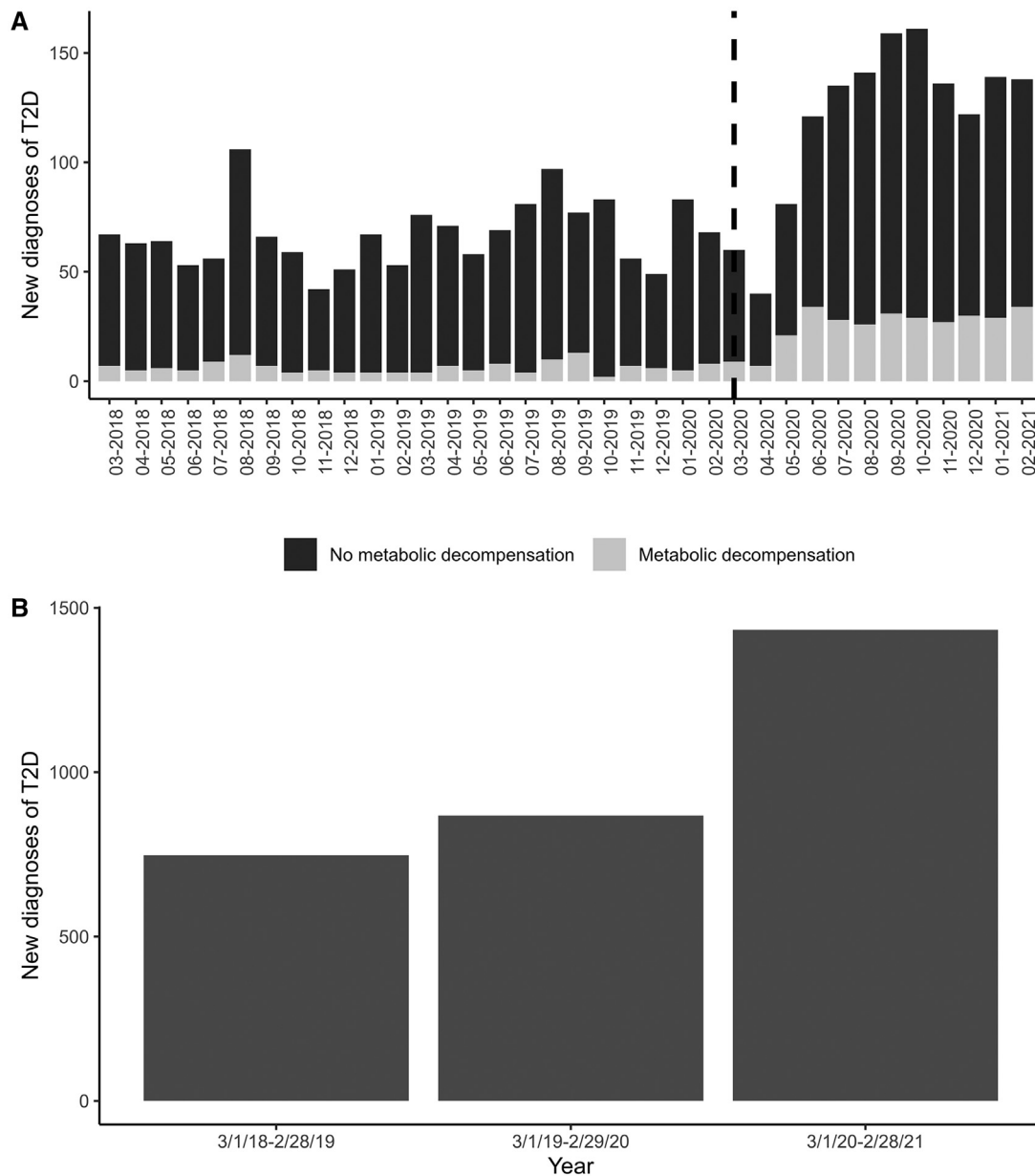


Figure 1. New youth-onset type 2 diabetes diagnosis by month and year. **A**, Number of new type 2 diabetes cases by month, including the proportion presenting with metabolic decompensation. The *dotted vertical line* demarcated onset of the COVID-19 pandemic. **B**, Total number of new diagnoses by year. *T2D*, type 2 diabetes.

any effect of seasonality. There was a difference in racial/ethnic distribution over the 3 years, $P = .004$ (Table 1, Figure 2), with post-hoc analyses demonstrating increased diagnoses among Black youth ($P = .002$) and decreased diagnoses among White youth ($P = .039$) during the pandemic year. The vast majority of new type 2 diabetes diagnoses occurred in those with public insurance during all 3 years. There was a reversal in the proportion of male vs female new diagnoses—55% female/45% male in PPY18-19 and PPY19-20 compared with 45% female/55% male during the pandemic year ($P < .001$, Figure 2). There was no difference in association of sex by race/ethnicity pre- and postpandemic.

BMI was statistically greater on presentation in the pandemic year compared with PPY1 and PPY2. Patients with new-onset type 2 diabetes presented with greater HbA1c (median 10.4% vs 9.3% [PPY1] and 9.7% [PPY2], $P < .001$) and greater blood glucose during the pandemic compared with the 2 previous years (median 286 mg/dL vs 240 mg/dL [PPY18-19] and 246 mg/dL [PPY19-20], $P < .001$). In the prepandemic years, more patients with new-onset type 2 diabetes were diagnosed as outpatients; there was a reversal during the pandemic year such that more patients were diagnosed and managed as inpatients (43% inpatient vs 57% outpatient during PPY18-19 and PPY19-20, as opposed to 57% inpatient and 43% outpatient

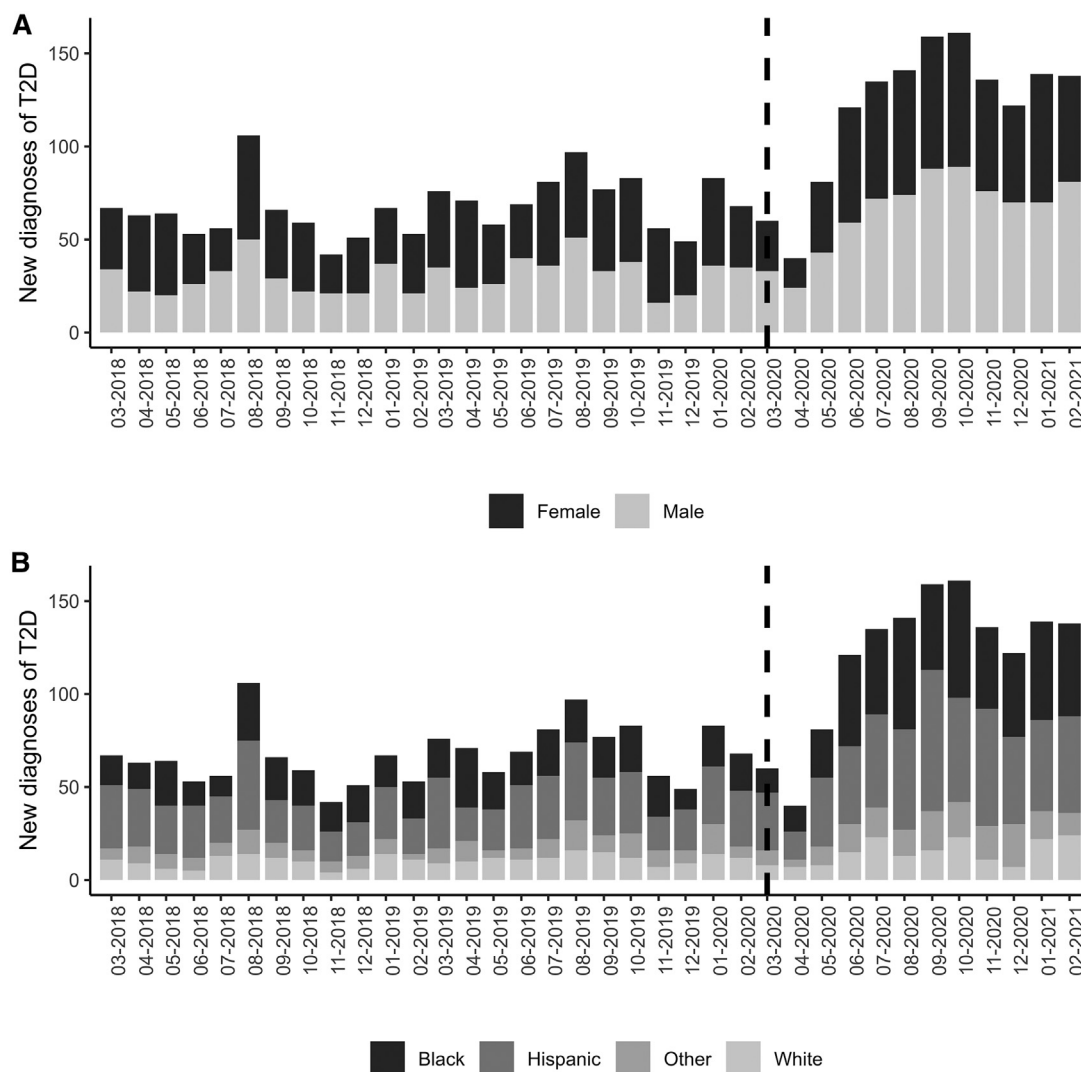


Figure 2. New youth-onset type 2 diabetes diagnosis by sex and race/ethnicity. **A**, Number of new cases each month broken down by sex, with the *dotted line* representing onset of the pandemic. This depicts the rise in proportion of male cases during the pandemic. **B**, Number of new cases each month broken down by race and ethnicity, with the *dotted line* representing onset of the pandemic. This depicts the relative rise in type 2 diabetes diagnoses in Black youth during the pandemic.

during the pandemic). Further, 21% of youth presented with metabolic decompensation (DKA and/or HHS) at diagnosis of type 2 diabetes during the first year of the pandemic compared with 9.4% and 9.0% in PPY1 and PPY2, respectively ($P < .001$) (Table I, Figure 1). Few patients in this cohort had a concurrent COVID-19 infection detected at presentation of type 2 diabetes (Table I).

A negative binomial time series model showed that pandemic onset (March 1, 2020) had a significant effect on the number of type 2 diabetes diagnoses, with a parameter estimate of 15.2, $P < .0001$. This estimate represents an increase of 15.2 type 2 diabetes cases per month, although the effect is not strictly additive because the background linear trend of 5% increase per year is applied to the increased number of cases per month. Another negative binomial time series model demonstrated a significant effect of the pandemic on

the number of patients presenting with metabolic decompensation, with a parameter estimate of 7.0, $P = .002$.

Discussion

This first multicenter report from 24 US diabetes centers, including more than 3100 youth diagnosed with new-onset type 2 diabetes over 3 years, shows an unprecedented impact of the COVID-19 pandemic on the frequency of diagnosis of youth-onset type 2 diabetes, increasing by 77.3% compared with the average in the 2 previous years. Moreover, severity of initial presentation rose, based on proportion presenting with metabolic decompensation, which more than doubled, and median HbA1c at diagnosis. This confirms the findings of 3 single-center studies, all of which contributed data to this analysis, suggesting that rates of type 2 diabetes

and presentation in DKA rose during the COVID-19 pandemic.^{11,14,15}

Although the incidence of type 2 diabetes was already on the rise, the increase seen in the past year significantly outpaces recently published epidemiologic data, which demonstrated an annual increase in incidence of approximately 5% between 2002 and 2012.¹ Interestingly, the rise in youth-onset type 2 diabetes between PPY18-19 and PPY19-20, at 15.8%, was also greater than previously reported. However, data presented here are derived from subspecialty diabetes care centers, and are not population-based data, so trends seen in this study may not be generalizable. Historically, type 2 diabetes has been described as almost twice as common among female youth in the US,^{1,20} but during the pandemic this trend changed, with an increase in the relative proportion of adolescent male youth diagnosed. There was also an increase in proportion of cases diagnosed in Black youth and a decrease in White youth during the pandemic. The sex differences seen do not appear to be driven by racial or ethnic differences. However, the increase in proportion of Black youth diagnosed with type 2 diabetes is consistent with recent US population data.²

Potential explanations for the pandemic-associated rise in youth-onset type 2 diabetes are broad and likely multifactorial. Pediatric weight gain tends to increase during summer months, when school is out.^{21,22} Indeed, there are regional^{23,24} and national^{25,26} database reports of a rising trajectory of BMI during the pandemic, when most youth were out of school, and BMI increases were greatest in youth with previous overweight or obesity. However, the rise in BMI appears to have had the most significantly affected younger children (5-11 years),²⁵ whereas the onset of type 2 diabetes seldom occurs before puberty. We noted an increase in BMI of youth at diabetes diagnosis in the pandemic year compared with the previous 2 years. The reasons for pandemic gains in BMI have yet to be elucidated but presumably are in part related to increases in sedentary behavior and changes in eating behaviors. During the pandemic, families reported changes in the home food environment, purchasing more shelf-stable foods that are ultra-processed and calorie-dense, which could contribute to weight gain.²⁷ Sedentary behavior changes included increased screen time related to online school, lack of physical education, cancellation of organized sports and other activities, and people being more confined to their homes.²⁸ One group specifically reported an increase in screen time during the pandemic in youth with previously diagnosed type 2 diabetes.²⁹ However, most of available data regarding pandemic-related behavior changes are based on self-report, relying on recall for report of prepandemic behaviors; thus, these are likely to be inaccurate.²⁸⁻³⁰ Accelerometry-based data from TODAY and National Health and Nutrition Examination Survey suggested that greater sedentary behavior distinguishes youth with type 2 diabetes from youth with obesity but without diabetes.³¹ Furthermore, boys are known to be more physically active than girls during adolescence^{32,33}; thus, they may have been affected in terms of BMI gains and metabolic risk by

increases in sedentary behavior than girls. This may, in part explain, the reversal in sex differences in incident type 2 diabetes in youth during the pandemic. Although there is some evidence that boys experienced greater weight gain during the pandemic,³⁴ the largest studies did not break results down by sex,^{24,25,35} so it is unclear whether boys had more significant weight gain than girls. However, data from the TODAY study support the hypothesis that lifestyle change may more significantly affect type 2 diabetes in adolescent boys, as male subjects in TODAY responded more favorably to lifestyle intervention than female subjects.³ Although this evidence is certainly not adequate to prove that lifestyle behavior changes are the sole cause of rising cases of youth-onset type 2 diabetes during the pandemic, they certainly may contribute to its onset in those at increased risk.

Another potential contributor to the pandemic-related increase in type 2 diabetes presentation is an increase in psychosocial stress.³⁶ Youth with type 2 diabetes are known to be exposed to significant environmental stressors, as evidenced by a high proportion coming from single-caregiver and low-income households, with low parental education attainment.²⁰ Furthermore, mental health disorders are common in youth with obesity and diabetes.^{37,38} It is possible that elements of this underlying stress could contribute to the pathophysiology of diabetes. Shomaker et al demonstrated that treatment of depression with cognitive behavioral therapy in girls at risk for type 2 diabetes improved insulin sensitivity compared with health education-controls 1 year after the treatment, and independent of BMI change.³⁹ Furthermore, in SEARCH, depression was associated with greater metabolic and inflammatory markers.⁴⁰ The COVID-19 pandemic has resulted in a significant mental health crisis in youth, with rates of depression and anxiety among youth that have doubled compared with prepandemic years.⁴¹ In addition, screens assessing suicide risk have shown increasing rates of positivity during the COVID-19 pandemic in both the pediatric emergency department⁴² and primary care setting.⁴³ In addition to potentially affecting stress physiology, social determinants of health also impact access to healthy food, access to health care, and safe outdoor environments. The pandemic may have disproportionately affected Black youth, who already are at greater risk for health disparities.⁴⁴ This may in part explain the racial differences in newly diagnosed diabetes associated with the pandemic. Whether there is a direct or indirect relationship between psychosocial stress and incident youth-onset type 2 diabetes, this coincident increase during the pandemic warrants further investigation.

Finally, there is a possibility that COVID-19 infection itself may have caused a nonautoimmune destruction of β cells, resulting in declines in β -cell function in adolescents already predisposed to develop diabetes. There is in vitro evidence that the β -cell expresses the angiotensin converting enzyme-2 receptor—the receptor that the severe acute respiratory syndrome coronavirus 2 virus binds to gain entry into the cell and, further, that COVID-19 infection in the β -cell can result in decreased insulin secretion.^{45,46} Some have

argued that this might explain high rates of DKA in adults with COVID-19 infection and coincident diabetes. However, the evidence is conflicting and purely in vitro in nature.⁴⁷ A recent publication from the Centers for Disease Control and Prevention using retrospective claims data in thousands of youth found a significant increase in diabetes incidence at least 30 days after COVID-19 infection, both compared with a control population without COVID-19 infection and compared with a pre-pandemic control group with non-COVID-19 respiratory infection.⁵ However, the study did not differentiate diabetes type. COVID-19 infection has been associated with an increase in type 2 diabetes onset among adults.^{48,49} Currently, an international group has designed a registry (CoviDIAB) to better evaluate the clinical impact of COVID-19 on incident type 2 diabetes.⁴⁹ In those hospitalized from our cohort, very few had coincident COVID-19 infection. Because symptomatic COVID-19 infections are low in youth, and antibody testing was very limited at our sites, our study lacks evidence for whether these youth with newly diagnosed type 2 diabetes had a previous COVID-19 infection.

Our results also demonstrated increased severity of presentation of youth-onset type 2 diabetes during the pandemic, with increased HbA1c on presentation and increased presentation with metabolic decompensation. Although criteria for inpatient admission of youth with new-onset type 2 diabetes varies by institution, and these criteria may have been impacted by the COVID-19 pandemic, inpatient admission generally suggests a more severe presentation at diagnosis. A pandemic-associated increase in severity of presentation also has been reported in youth with type 1 diabetes.^{7,8,14,49} It is also likely that patients and families may have delayed seeking care due to concerns about being exposed to COVID-19; delayed presentation with other diseases has been reported in the literature.^{50,51} Whereas the literature on adult reports increased DKA rates in those with a previous diabetes diagnosis associated with concurrent COVID-19 infection, as well as hyperglycemia associated with COVID-19 infection in patients without diabetes, detected rates of COVID-19 positivity were low in our patients presenting with metabolic decompensation.

This study has the known limitations of retrospective chart review data, which include inconsistency of reported data and missing information. In addition, incidence data cannot be derived due to lack of an appropriate denominator. Thus, the findings need to be validated in population-based cohorts. One of the strengths is the use of a rigorous type 2 diabetes definition, requiring at least 2 pancreatic autoantibodies tested and negative, without positive detected antibodies. This, combined with the pediatric endocrinology provider-based diagnosis, ensures that patients with type 2 diabetes were captured in this analysis. Another strength is the racial/ethnic and geographic heterogeneity of the study population, which is possible only with multicenter data

from centers throughout the US. In addition, the findings confirm what single sites have previously reported.

The results of this study of more than 3100 patients with newly diagnosed diabetes demonstrate a dramatic impact of the COVID-19 pandemic on the presentation of type 2 diabetes in youth, which was already rising in incidence and prevalence before the pandemic. This has created a significant strain on pediatric endocrinology, general practitioner, and obesity providers, who have been managing this growing population with limited resources. Moreover, marginalized and under-resourced families already impacted by high rates of unemployment, food and housing insecurity during the pandemic, have been disproportionately affected. The long-term implications of this rapid rise in youth-onset type 2 diabetes case numbers are important in the context of the final outcome analysis of the TODAY study, which demonstrated an alarming incidence of complications—60% of youth experienced at least 1 complication after a mean follow-up of 13.3 years.⁴ It is important to note that the TODAY study participants were treated and followed rigorously as part of a clinical trial and, thus, results may underestimate the burden of complications in youth-onset type 2 diabetes. Follow-up studies will need to assess durability of the trend of increasing type 2 diabetes case numbers and severity, and to further explore potential underlying causes and outcomes. ■

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Reprint requests: Megan M. Kelsey, MD, MS, 13123 E 16th Ave, B265, Aurora, CO 80045. E-mail: megan.kelsey@childrenscolorado.org

References

1. Mayer-Davis EJ, Lawrence JM, Dabelea D, Divers J, Isom S, Dolan L, et al. Incidence Trends of type 1 and type 2 diabetes among youths, 2002-2012. *N Engl J Med* 2017;376:1419-29.
2. Lawrence JM, Divers J, Isom S, Saydah S, Imperatore G, Pihoker C, et al. Trends in prevalence of type 1 and type 2 diabetes in children and adolescents in the US, 2001-2017. *JAMA* 2021;326:717-27.
3. Zeitler P, Hirst K, Pyle L, Linder B, Copeland K, Arslanian S, et al. A clinical trial to maintain glycemic control in youth with type 2 diabetes. *N Engl J Med* 2012;366:2247-56.
4. Group TS, Bjornstad P, Drews KL, Caprio S, Gubitosi-Klug R, Nathan DM, et al. Long-term complications in youth-onset type 2 diabetes. *N Engl J Med* 2021;385:416-26.
5. Barrett CE, Koyama AK, Alvarez P, Chow W, Lundeen EA, Perrine CG, et al. Risk for Newly diagnosed diabetes >30 days after sARS-CoV-2 infection among persons aged <18 years—United States, March 1, 2020-June 28, 2021. *MMWR Morb Mortal Wkly Rep* 2022;71:59-65.
6. Beliard K, Ebekozién O, Demeterco-Berggren C, Alonso GT, Gallagher MP, Clements M, et al. Increased DKA at presentation among newly diagnosed type 1 diabetes patients with or without COVID-19: data from a multi-site surveillance registry. *J Diabetes* 2021;13:270-2.
7. Kamrath C, Mönkemöller K, Biester T, Rohrer TR, Warncke K, Hammersen J, et al. Ketoacidosis in children and adolescents with newly diagnosed type 1 diabetes during the COVID-19 pandemic in Germany. *JAMA* 2020;324:801-4.

8. Rabbone I, Schiaffini R, Cherubini V, Maffei C, Scaramuzza A. Has COVID-19 delayed the diagnosis and worsened the presentation of type 1 diabetes in children? *Diabetes Care* 2020;43:2870-2.
9. Tittel SR, Rosenbauer J, Kamrath C, Ziegler J, Reschke F, Hammersen J, et al. Did the COVID-19 lockdown affect the incidence of pediatric type 1 diabetes in Germany? *Diabetes Care* 2020;43:e172-3.
10. Unsworth R, Wallace S, Oliver NS, Yeung S, Kshirsagar A, Naidu H, et al. New-onset type 1 diabetes in children during COVID-19: multicenter regional findings in the U.K. *Diabetes Care* 2020;43:e170-1.
11. Chao LC, Vidmar AP, Georgia S. Spike in diabetic ketoacidosis rates in pediatric type 2 diabetes during the COVID-19 pandemic. *Diabetes Care* 2021;44:1451-3.
12. Modarelli R, Sarah S, Ramaker ME, Bolobiongo M, Benjamin R, Gumus Balikcioglu P. Pediatric diabetes on the rise: trends in incident diabetes during the COVID-19 pandemic. *J Endocr Soc* 2022;6:bvac024.
13. Schmitt JA, Ashraf AP, Becker DJ, Sen B. Changes in type 2 diabetes trends in children and adolescents during the COVID-19 pandemic. *J Clin Endocrinol Metab* 2022;107:e2777-82.
14. Marks BE, Khilnani A, Meyers A, Flokas ME, Gai J, Monaghan M, et al. Increase in the diagnosis and severity of presentation of pediatric type 1 and type 2 diabetes During the COVID-19 pandemic. *Horm Res Paediatr* 2021;94:275-84.
15. Neyman A, Nabhan Z, Woerner S, Hannon T. Pediatric Type 2 diabetes presentation during the COVID-19 pandemic. *Clin Pediatr (Phila)* 2021. 99228211064030.
16. American Diabetes Association. 2. Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes—2021. *Diabetes Care* 2021;44:S15-33.
17. Wolfsdorf JJ, Glaser N, Agus M, Fritsch M, Hanas R, Rewers A, et al. ISPAD Clinical Practice Consensus Guidelines 2018: diabetic ketoacidosis and the hyperglycemic hyperosmolar state. *Pediatr Diabetes* 2018;19(suppl 27):155-77.
18. Fokianos K, Fried R. Interventions in INGARCH processes. *J Time Series Analysis* 2010;31:210-25.
19. Fokianos K, Fried R. Interventions in log-linear Poisson autoregression. *Stat Modelling* 2012;12:299-322.
20. Copeland KC, Zeitler P, Geffner M, Guandalini C, Higgins J, Hirst K, et al. Characteristics of adolescents and youth with recent-onset type 2 diabetes: the TODAY cohort at baseline. *J Clin Endocrinol Metab* 2011;96:159-67.
21. Franckle R, Adler R, Davison K. Accelerated weight gain among children during summer versus school year and related racial/ethnic disparities: a systematic review. *Prev Chronic Dis* 2014;11:E101.
22. Moreno JP, Johnston CA, Woehler D. Changes in weight over the school year and summer vacation: results of a 5-year longitudinal study. *J Sch Health* 2013;83:473-7.
23. Jenssen BP, Kelly MK, Powell M, Bouchelle Z, Mayne SL, Fiks AG. COVID-19 and Changes in Child Obesity. *Pediatrics* 2021;147. e2021050123.
24. Woolford SJ, Sidell M, Li X, Else V, Young DR, Resnicow K, et al. Changes in body mass index among children and adolescents during the COVID-19 pandemic. *JAMA* 2021;326:1434-6.
25. Lange SJ, Kompaniyets L, Freedman DS, Kraus EM, Porter R, Blanck HM, et al. Longitudinal trends in body mass index before and during the COVID-19 pandemic among persons aged 2–19 years—United States, 2018–2020. *MMWR Morb Mortal Wkly Rep* 2021;70:1278-83.
26. Weaver RG, Hunt ET, Armstrong B, Beets MW, Brazendale K, Turner-McGrievy G, et al. COVID-19 leads to accelerated increases in children's BMI z-score gain: an interrupted time-series study. *Am J Prev Med* 2021;61:e161-9.
27. Adams EL, Caccavale LJ, Smith D, Bean MK. Food insecurity, the home food environment, and parent feeding practices in the era of COVID-19. *Obesity* 2020;28:2056-63.
28. Pietrobelli A, Pecoraro L, Ferruzzi A, Heo M, Faith M, Zoller T, et al. Effects of COVID-19 lockdown on lifestyle behaviors in children with obesity living in Verona, Italy: a longitudinal study. *Obesity* 2020;28:1382-5.
29. Cheng HP, Wong JSL, Selveindran NM, Hong JYH. Impact of COVID-19 lockdown on glycaemic control and lifestyle changes in children and adolescents with type 1 and type 2 diabetes mellitus. *Endocrine* 2021;73:499-506.
30. Dunton GF, Do B, Wang SD. Early effects of the COVID-19 pandemic on physical activity and sedentary behavior in children living in the U.S. *BMC Public Health* 2020;20:1351.
31. Kriska A, Delahanty L, Edelstein S, Amodei N, Chadwick J, Copeland K, et al. Sedentary behavior and physical activity in youth with recent onset of type 2 diabetes. *Pediatrics* 2013;131:e850-6.
32. Basterfield L, Adamson AJ, Frary JK, Parkinson KN, Pearce MS, Reilly JJ. Longitudinal study of physical activity and sedentary behavior in children. *Pediatrics* 2011;127:e24-30.
33. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA* 2008;300:295-305.
34. Maltoni G, Zioutas M, Deiana G, Biserni GB, Pession A, Zucchini S. Gender differences in weight gain during lockdown due to COVID-19 pandemic in adolescents with obesity. *Nutr Metab Cardiovasc Dis* 2021;31:2181-5.
35. Brooks CG, Spencer JR, Sprafka JM, Roehl KA, Ma J, Londhe AA, et al. Pediatric BMI changes during COVID-19 pandemic: an electronic health record-based retrospective cohort study. *EclinicalMedicine* 2021;38:101026.
36. Patrick SW, Henkhaus LE, Zickafoose JS, Lovell K, Halvorson A, Loch S, et al. Well-being of parents and children during the COVID-19 pandemic: a national survey. *Pediatrics* 2020;146:e2020016824.
37. Gully LD, Shomaker LB. Depression in youth-onset type 2 diabetes. *Curr Diab Rep* 2020;20:51.
38. Rankin J, Matthews L, Coble S, Han A, Sanders R, Wiltshire HD, et al. Psychological consequences of childhood obesity: psychiatric comorbidity and prevention. *Adolesc Health Med Ther* 2016;7:125-46.
39. Shomaker LB, Tanofsky-Kraff M, Stern EA, Miller R, Zocca JM, Field SE, et al. Longitudinal study of depressive symptoms and progression of insulin resistance in youth at risk for adult obesity. *Diabetes Care* 2011;34:2458-63.
40. Hood KK, Lawrence JM, Anderson A, Bell R, Dabelea D, Daniels S, et al. Metabolic and inflammatory links to depression in youth with diabetes. *Diabetes Care* 2012;35:2443-6.
41. Racine N, McArthur BA, Cooke JE, Eirich R, Zhu J, Madigan S. Global prevalence of depressive and anxiety symptoms in children and adolescents during COVID-19: a meta-analysis. *JAMA Pediatr* 2021;175:1142-50.
42. Hill RM, Rufino K, Kurian S, Saxena J, Saxena K, Williams L. Suicide ideation and attempts in a pediatric emergency department before and during COVID-19. *Pediatrics* 2021;147:e2020029280.
43. Mayne SL, Hannan C, Davis M, Young JF, Kelly MK, Powell M, et al. COVID-19 and adolescent depression and suicide risk screening outcomes. *Pediatrics* 2021;148. e2021051507.
44. Hill-Briggs F, Adler NE, Berkowitz SA, Chin MH, Gary-Webb TL, Navas-Acien A, et al. Social determinants of health and diabetes: a scientific review. *Diabetes Care* 2021;44:258-79.
45. Tang X, Uhl S, Zhang T, Xue D, Li B, Vandana JJ, et al. SARS-CoV-2 infection induces beta cell transdifferentiation. *Cell Metab* 2021;33:1577-91.e7.
46. Wu C-T, Lidsky PV, Xiao Y, Lee IT, Cheng R, Nakayama T, et al. SARS-CoV-2 infects human pancreatic β cells and elicits β cell impairment. *Cell Metab* 2021;33:1565-76.e5.
47. Accili D. Can COVID-19 cause diabetes? *Nat Metab* 2021;3:123-5.
48. Al-Aly S, Xie Y, Bowe B. High-dimensional characterization of post-acute sequelae of COVID-19. *Nature* 2021;594:259-64.
49. Rubino F, Amiel SA, Zimmet P, Alberti G, Bornstein S, Eckel RH, et al. New-onset diabetes in Covid-19. *N Engl J Med* 2020;383:789-90.

50. Lazerini M, Barbi E, Apicella A, Marchetti F, Cardinale F, Trobia G. Delayed access or provision of care in Italy resulting from fear of COVID-19. *Lancet Child Adolesc Health* 2020;4:e10-1.
51. Rosenberg Danziger C, Krause I, Scheurman O, Luder A, Yulevich A, Dalal I, et al. Pediatrician, watch out for corona-phobia. *Eur J Pediatr* 2021;180:201-6.

50 Years Ago in *THE JOURNAL OF PEDIATRICS*

Toward a Better Understanding of Infections Acquired in a Pediatric Hospital

Gardner P, Carles DG. Infections acquired in a pediatric hospital. *J Pediatr* 1972;81:1205-10.

The publication of this study by Gardner and Carles in 1972 began a long journey toward improved infection-prevention measures for hospitalized children. The goal of their study was to determine the overall incidence, site of infection, patient characteristics, and severity of disease over a 1-year period at a 343-bed children's hospital. Their data showed that 3.2% of children admitted were diagnosed with a hospital-acquired infection, with surgical-site infections the most common and gram-negative organisms the leading pathogens. In addition, during the study period, the authors noted a cluster of clinically diagnosed measles, an outbreak of salmonella associated with contaminated enteral feeds, and several cases of *Erwinia* bacteremia, likely due to contaminated intravenous fluids.

Over the last 50 years, the US has created an organized infrastructure to support infection-prevention efforts. The Centers for Disease Control and Prevention manage the National Healthcare Safety Network, which hospitals use to report hospital-acquired infections. Advances in microbiologic and molecular diagnostic techniques have been instrumental in rapid surveillance. To understand the great importance of early pathogen identification, one only needs to consider the challenges faced in slowing the spread of severe acute respiratory syndrome coronavirus 2 when rapid testing was not available. Surgical-site infections in children have been reduced over time with the implementation of perioperative antibiotics and skin preparation with chlorhexidine. Without a surveillance system, it would have been difficult to understand the burden of disease across institutions and to effect broad-based practice changes.

Although we have made progress toward understanding pediatric hospital-acquired infections, there is still work to be done. Compared with adult hospitals, children's hospitals have a greater percentage of admissions for community-acquired respiratory viral infections, increasing the risk of nosocomial transmission. Efforts to understand the incidence and morbidity associated with health care-associated respiratory viral infections have been limited by interhospital variability. In addition, there is no agreed-on surveillance definition, and most states do not require the reporting of health care-associated respiratory viral infections.¹ One lesson from the work of Gardner and Carles is that we should recognize the importance of hospital-acquired infection surveillance that addresses the unique needs of the pediatric population.

Salih Demirhan, MD

Margaret L. Aldrich, MD

Division of Pediatric Infectious Diseases
Children's Hospital at Montefiore
Albert Einstein College of Medicine
Bronx, New York

Reference

1. Most ZM, Jackson P, Sebert M, Perl TM. Contrasting definitions and incidence of healthcare-associated respiratory viral infections in a pediatric hospital. *Infect Control Hosp Epidemiol* 2022;1-7. <https://doi.org/10.1017/ice.2022.33>

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L.H. is a site investigator for a type 2 diabetes treatment trial sponsored by Boehringer-Ingelheim; M.K. is a site investigator for type 2 diabetes treatment trials sponsored by Boehringer-Ingelheim and Janssen; B.M. has received

investigator-initiated funding from Tandem Diabetes Care and Dexcom; A.S. is the site PI for trials sponsored by AstraZeneca, NovoNordisk, and Boehringer-Ingelheim; and R.W. has received investigator-initiated funding from Dexcom; the other authors declare no conflicts of interest.

Table II. Number of new cases by year at each site (%of total for that year)

Institutions	March 1, 2018, to February 28, 2019 N = 764	March 1, 2019, to February 28, 2020 N = 886	March 1, 2020, to February 28, 2021 N = 1463
Children's Hospital Colorado	59 (7.7)	61 (6.9)	95 (6.5)
Children's Hospital Illinois	2 (0.3)	4 (0.5)	4 (0.3)
Children's Hospital Los Angeles	86 (11.3)	130 (14.7)	210 (14.4)
Children's Hospital Philadelphia	21 (2.7)	42 (4.7)	72 (4.9)
Children's Mercy	35 (4.6)	59 (6.7)	69 (4.7)
Children's National Hospital	39 (5.1)	30 (3.4)	86 (5.9)
Cincinnati Children's Hospital	38 (5.0)	41 (4.6)	45 (3.1)
Columbia University Irving Medical Center, Harlem Hospital	8 (1.0)	13 (1.5)	27 (1.8)
Duke University Medical Center	3 (0.4)	3 (0.3)	20 (1.4)
Hasbro Children's Hospital	18 (2.4)	19 (2.1)	37 (2.5)
John Hopkins Hospital	25 (3.3)	24 (2.7)	57 (3.9)
Lurie Children's Hospital	52 (6.8)	33 (3.7)	101 (6.9)
Mayo Clinic	5 (0.7)	5 (0.6)	9 (0.6)
Our Lady of The Lake Children's Hospital	17 (2.2)	20 (2.3)	23 (1.6)
Penn State Health Children's Hospital	17 (2.2)	19 (2.1)	32 (2.2)
Rady Children's Hospital	43 (5.6)	47 (5.3)	98 (6.7)
Riley Children's Hospital	35 (4.6)	42 (4.7)	62 (4.2)
Texas Children's Hospital	31 (4.1)	32 (3.6)	43 (2.9)
University of California San Francisco	46 (6.0)	64 (7.2)	92 (6.3)
University of Chicago Medical Center	20 (2.6)	20 (2.3)	41 (2.8)
University of Michigan	14 (1.8)	10 (1.1)	11 (0.8)
University of Oklahoma Health Sciences Center	42 (5.5)	55 (6.2)	67 (4.6)
University of Texas Southwestern	91 (11.9)	95 (10.7)	132 (9.0)
Vanderbilt University Medical Center	17 (2.2)	18 (2.0)	30 (2.1)