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Youth-Onset Type 2 Diabetes: Burden of Complications and Socioeconomic Cost

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Abstract

Purpose of Review With the rise in prevalence of youth-onset type 2 diabetes (T2DM), it is imperative to understand the clinical burden of the disease and the socioeconomic burden this disease imposes. We review the most recent data on youth-onset T2DM, including its pathophysiology, complications, and treatment. We also review existing data to determine the socioeconomic burden of youth-onset T2DM.

Recent Findings The incidence of youth-onset T2DM is rising, and significantly accelerated following the COVID-19 pandemic. Youth with T2DM are more frequently from families of racial/ethnic minorities and lower socioeconomic status. Youth-onset T2DM has more rapid disease progression compared to adult-onset type 2 diabetes. It results in earlier and more severe microvascular and macrovascular complications compared to both adult-onset T2DM and youth-onset type 1 diabetes (T1DM). While there is a lack of data describing the socioeconomic cost of youth-onset T2DM, based on extrapolation from analyses of the burden of T2DM in adults and T1DM in youth, we propose that youth-onset T2DM has higher direct and indirect costs than adult-onset T2DM.

Summary Youth-onset T2DM presents a significant clinical and socioeconomic burden due to its aggressive presentation and earlier appearance of complications. Additional research is needed regarding the cost of illness in this population.

Keywords Youth-onset type 2 diabetes · Cost of diabetes

Introduction

While type 2 diabetes (T2DM) has been previously considered a serious "adult chronic health condition," T2DM is also seen in adolescents. Along with the rise in obesity among youth, T2DM is becoming more frequent among adolescents, and this trend is projected to continue [1]. It is clear that the phenotype of youth-onset T2DM is more severe than what is seen in adults and that complications and adverse clinical outcomes occur earlier [2]. Complications are also more frequently seen in youth-onset T2DM compared to those with youth-onset type 1 diabetes (T1DM) [3]. Although treatment options are expanding with recent approval for the use of glucagon-like peptide 1 receptor agonist (GLP-1RA) in youth, overall treatment options for youth with T2DM are limited compared to what is available for adults with T2DM. Furthermore, youth with T2DM have significant barriers to care and non-adherence to medications, making treatment challenging [4]. With this in mind, it is important to understand not only the clinical consequences of youth-onset T2DM, but also the socioeconomic implications of this severe disease, which is becoming increasingly prevalent, particularly among racial and ethnic minority groups.

Epidemiology

Over the last 20 years, there has been a notable increase in both the incidence and prevalence of youth-onset T2DM. According to the *SEARCH for Diabetes in Youth Study*,

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incidence of type 2 diabetes among youths between the ages of 10 and 19 increased from 9 cases per 100,000 youths per year in 2002–2003 to 12.5 cases per 100,000 youths per year in 2011–2012. This equates to an annual increase of 7.1% observed across all age, sex, race, or ethnic groups [5]. The prevalence of youth-onset T2DM among children aged 10–19 years is 0.67 per 1000 youths [1]. This increased from 0.34 in 2001, representing a relative increase of 95.3% over 16 years. This increased prevalence was noted in all subgroups by age, race, and ethnicity except for White youths, with the most significant increase in prevalence among Black youth and Hispanic females ages 10–14 years old [1].

In addition to the rise in the prevalence of T2DM among youth, an analysis utilizing National Health and Nutrition Examination Survey (NHANES) data for 2005–2016 estimated the prevalence of prediabetes to be 1 in 5 adolescents aged 12 to 18 years. Adolescent males are almost two times more affected than females, and non-Hispanic black adolescents have higher rates of elevated HbA1C when compared with Hispanic and non-Hispanic white individuals [6].

The prevalence of prediabetes and T2DM in youth has risen in parallel with an increase in childhood obesity and other obesity-related comorbidities, including obstructive sleep apnea, dyslipidemia, and hypertension. Severe obesity has risen significantly among children aged 2–5 and adolescent females aged 16–19 [7]. Non-Hispanic African American and Hispanic children are disproportionally affected with a higher prevalence of all classes of obesity when compared to other ethnicities [7]. Despite public health interventions to attempt to mitigate childhood obesity, it is projected that by 2030 approximately 33% of children ages 6–11 and 50% of adolescents up to 19 will have excess weight [8].

The growing prevalence and incidence of youth-onset T2DM have shed light on the growing racial and ethnic disparities of the disease. Most T2DM in youth is in those of racial and ethnic minorities. Specifically, approximately 80% of youth with T2DM are from backgrounds of racial/ethnic minorities [9]. In addition, families of youth with T2DM are more likely to have low parental educational attainment and low family socioeconomic status. Lessons from the "Treatment Options for Type 2 Diabetes in Adolescents & Youth" (TODAY) trial indicate that approximately 40% of families of youth with T2DM had a family income of $25,000 per year or less [10]. These negative social determinants of health likely contribute to poorer outcomes in youth with T2DM, perpetuating a cycle of lower socioeconomic status, higher prevalence of comorbidities, and poorer quality of life.

More recently, the COVID-19 pandemic has been associated with a further rise in the incidence of T2DM in youth and an acute increase in the severity of the disease at initial presentation. A study that analyzed retrospective data from 24 pediatric hospitals across the USA found that T2DM in youth increased by 77.3% in the initial year after the COVID-19 pandemic, compared to the two years pre-pandemic, before March 2020 [11]. The data reinforced what was previously known regarding the racial disparities of youth-onset T2DM where ethnic minorities continue to be the most affected particularly Black youth. It was also noted that most new diagnoses of youth-onset T2DM were among individuals with public insurance (76%) compared to other types of payers [11••].

Given the increase in youth-onset T2DM, the SEARCH for Diabetes in Youth Study set out to project the future burden of the disease [12••]. In this study, the incidence trend of youth-onset diabetes was postulated using different scenarios: a constant incidence scenario with no change in incidence rate between 2017 and 2060 versus an increasing incidence scenario where the trend in incidence observed in SEARCH between 2002 and 2017 would continue until 2060 [12••]. In the constant incidence scenario, the number of youths with T2DM is projected to increase from 28,000 to 48,000 youth and to 220,000 youth in the increasing incidence scenario [12••]. This study also predicts that the racial and ethnic disparities among youth with T2DM will continue to widen [12••].

Pathophysiology

The main etiologic basis of the development of T2DM in youth is similar to what is seen in adults: an increase in insulin resistance, which leads to compensatory hyperinsulinemia with eventual defective insulin secretion through the failure of pancreatic beta cells. The interplay of genetic and environmental factors leads to its presentation. More than 65 genetic variants are known to influence the development of T2DM [13]. One of the most significant risk factors contributing to insulin resistance is obesity, which is influenced by excess caloric intake and a sedentary lifestyle.

In youth, the onset of puberty is a primary risk factor due to the temporary decrease in insulin sensitivity related to increased growth hormone production. Youth-onset T2DM is rarely diagnosed before puberty and is most commonly seen in adolescents during mid-puberty. The median age of onset is 13.5 years which coincides with this peak of physiological insulin resistance [3].

In addition to direct genetic and environmental factors, it is becoming increasingly evident that the quality of the intrauterine environment can influence lifelong diabetes risk. Maternal gestational diabetes and maternal obesity are strongly associated with an increased risk of the development of T2DM in offspring. The TODAY study showed that children of mothers with diabetes were diagnosed with diabetes at younger ages and had worse beta cell function [14]. A secondary analysis of the TODAY cohort demonstrated

that maternal diabetes history was associated with worse glycemic control, increased markers of autonomic neuropathy, and increased glomerular hyperfiltration [15]. It has been proposed that exposure to suboptimal environments during gestation influences epigenetic modifications during development, which can adversely affect metabolic programming [16].

Although the pathophysiology of T2DM in youth is similar to that in adults, there is evidence that youth-onset diabetes is more aggressive, with severe insulin resistance and more rapid disease progression. The RISE consortium demonstrated through studies with hyperglycemic clamp methodology [17] and oral glucose tolerance tests (OGTTs) [18] that youth with prediabetes or early-onset T2DM had around 50% lower insulin sensitivity than adults. In addition, dysglycemia worsened more frequently in youth than in adults. It has also been noted that when comparing treatment responses between youth and adults, there is a progressive decline in beta-cell function in response to an oral glucose challenge and worsening HbA1C in youth. In contrast, beta-cell function in adults remained relatively stable over 21 months [19].

Complications and Comorbidities

Through studies such as TODAY [20••] and Restoring Insulin Secretion (RISE) [17–19], it is known that youth-onset T2DM has a high incidence of complications which has been linked to its more severe metabolic phenotype, including severe insulin resistance and rapidly progressive decline in beta-cell function. Complications appear early, with approximately 60.1% of participants having at least one microvascular complication and 28.4% of participants having two or more diabetes complications at a mean age of 26.4 years, according to TODAY [20••]. Factors associated with an increased risk of complications were hyperglycemia, low insulin sensitivity, hypertension, dyslipidemia, and minority race or ethnic group [20••].

Adolescents and young adults with T2DM have a higher age-adjusted prevalence of complications when compared to those with type 1 diabetes (T1DM). These complications include diabetic kidney disease, retinopathy, peripheral neuropathy, arterial stiffness, and hypertension [21]. According to an observational study of 2018 adolescents and young adults in the USA diagnosed with T1 or T2DM at the early average age of 21 years with a mean diabetes duration of 7.9 years, approximately 3 out of 4 patients with youth-onset T2DM had at least one documented complication, compared to only 1 in 3 patients with T1DM of the same duration of disease [21].

A comprehensive systematic review of adult patients with T2DM determined an inverse relationship exists between the age at diabetes diagnosis and the risk of major diabetes complications after adjustments for actual age. With each 1-year increase in age at diabetes diagnosis, there is an associated decreased risk of all-cause mortality (4%), macrovascular disease (3%), and microvascular disease (5%) [22]. A noted limitation is that this data is from an older population and may not reflect the pathophysiology of youth-onset T2DM [22].

Given the role of poor glycemic control on the appearance of complications, it is important to assess predictors of glycemic failure in youth with T2DM. An observational follow-up study at 48 months of the TODAY cohort, TODAY2, determined that predictors of loss of glycemic control include the maternal history of diabetes and rise in HbA1C more than 0.5% over any interval, even if overall glycemic control appears to be within accepted standards for treatment regimen [23]. Identifying patients at risk for inadequate glycemic control and targeting more aggressive diabetes management in this population are essential to reduce the risk of complications.

Diabetic Kidney Disease

Diabetic kidney diseases, along with cardiovascular disease, are the greatest risk factors for both morbidity and mortality in T2DM [24]. Diabetic kidney disease mainly occurs from damage to the glomerulus due to factors such as hyperglycemia and hypertension [24]. Inadequate glycemic control with higher levels of HbA1C directly contributes to the development of albuminuria in patients with T2DM.

In youth with type 2 diabetes, early diabetic kidney disease, which includes hyperfiltration and albuminuria, is common. The TODAY study reported that youth with T2DM have hyperfiltration at diagnosis 8% of the time. Hyperfiltration, a feature predictive of subsequent development of albuminuria, is defined as the $\geq$ 99th percentile of estimated glomerular filtration rate [eGFR $\geq$ 140 mL/min/1.73 m^2] when referenced to healthy adolescents. The follow-up TODAY2 study reported the cumulative incidence of albuminuria in the TODAY cohort was 54.8% after only 15 years of having diabetes [20••]. In comparison with adults with T2DM, the UKPDS noted a baseline prevalence of microalbuminuria of 6.55% [25]. Ten years after diabetes diagnosis, the prevalence of kidney disease in adults was around 30% (25% microalbuminuria, 5% macroalbuminuria, and < 1% on renal replacement therapy).

In the previously discussed observational study comparing the prevalence of complications between youth diagnosed with T2DM vs T1DM < 20 years old, it was found that of 19.9% of participants with T2DM had diabetic kidney disease, compared to 5.8% with T1DM, despite a similar disease duration (7.9 years) [21].

Diabetic Neuropathy

Diabetes is associated with the development of peripheral and autonomic neuropathies with the most common being distal symmetric polyneuropathy (DPN) [24]. In youth with T2DM, SEARCH estimated the prevalence of neuropathy to be between 22 and 26% [21]. When compared to those with T1DM, those with youth-onset T2DM had a higher prevalence of peripheral neuropathy (8.5% vs 17.7% respectively) [21]. In a longitudinal follow-up study of participants from the TODAY study, 3.1% had, at baseline, an abnormal score via the Michigan Neuropathy Screening Instrument (MNSI) exam and the prevalence of DPN rose steadily with 25.4% of participants having abnormal MNSI exam at year 14 [26]. In addition, there was a 15% increase in the odds of having an abnormal MNSI-exam score over time with each 1 unit increase in HbA1C [26].

Youth-onset T2DM can also present with complications such as cardiac autonomic neuropathy due to the effect on autonomic nerves innervating blood vessels and the heart [24]. Data from the SEARCH for Diabetes in Youth Study estimated the prevalence of cardiac autonomic neuropathy as 17% for patients with T2DM. Cardiovascular autonomic neuropathy has been shown to be a predictor of cardiovascular disease and mortality risk [27].

Diabetic Retinopathy

Diabetic retinopathy (DR) is the leading cause of blindness in adults and the most frequent microvascular complication of diabetes [28]. Stages of diabetic retinopathy range from very mild to severe in non-proliferative diabetic retinopathy, proliferative diabetic retinopathy, and macular edema.

The TODAY study reported a 13.7% prevalence of DR in youth with T2DM after approximately 5-years duration [29]. As part of the follow-up study, the prevalence of retinal disease increased to 51.0%; of these 8.8% had moderate to severe retinal changes and 3.5% had macular edema [20••].

The SEARCH for Diabetes in Youth Study found an age-adjusted prevalence of diabetic retinopathy of 9.1% in youth-onset T2DM, a Fig. 3.5% higher than what was seen in youth-onset T1DM [21]. There is a higher prevalence of retinopathy noted among minority youth with T2DM [21].

Dyslipidemia

Dyslipidemia is frequently seen in youth with T2DM and usually consists of elevated triglycerides, low HDL-C, and elevated LDL-C [30]. The presence of dyslipidemia in those with DM is associated with the development of retinopathy, neuropathy, and nephropathy. According to a longitudinal follow-up study of TODAY participants, dyslipidemia was present in 20.8% or participants at baseline with a cumulative incidence at 15 years of 51.6% [20••].

Depression

Adolescents with diabetes are at increased risk for depression, and depressive symptoms have been linked to poor glycemic management [31]. A study assessing self-reported depressive symptoms among youth with T1DM and T2DM noted that adolescents with T2DM had higher depressive symptom scores and worse self-rated global health than adolescents with T1DM [31]. A study by the Pediatric Diabetes Consortium found that youth with T2DM had double the number of depressive symptoms compared to those with T1DM [32]. The longer the diabetes duration in youth with T2DM, the more severe the depression symptoms, which was not seen in youth with T1DM [31].

"Diabetes distress" is defined as the negative feelings and emotional burdens associated with living with the demands of diabetes [33]. Utilizing the Diabetes Distress Scale, the TODAY2 noted that among those with youth-onset T2DM, female sex, moderate to severe anxiety symptoms, and lack of health care coverage were associated with high diabetes distress after adjusting for race/ethnicity, education, BMI, insulin use, hypertension, retinopathy, and depressive symptoms. It was also noted that HbA1C was associated with diabetes distress; for every 1 unit increase in HbA1C, there was 30% higher odds of having high diabetes distress. Overall, in this cohort, 24% reported a clinically significant level of diabetes distress and depressive symptoms were associated with higher levels of overall distress [34].

Cardiovascular

Diabetes is associated with increased cardiovascular morbidity and mortality. Among youth with T2DM, there is a high prevalence of major cardiovascular risk factors [35]. A longitudinal follow-up of the TODAY and TODAY2 cohorts noted that the cumulative incidence of hypertension over 14 years was 59%, and HTN was more prevalent among those with higher BMI and HbA1C. Over 14 years, the cumulative incidence of LDL-C dyslipidemia was 33% and that of hypertriglyceridemia was 37% [36]. The high incidence of these major cardiovascular risk factors among youth with T2DM implies significant cardiovascular risk in the third and fourth decades of life [36].

When a cross-sectional analysis of participants in the SEARCH study was done to evaluate left ventricular structure and diastolic function in young adults with youth-onset diabetes, those with T2DM had higher left ventricular mass index and relative wall thickness as well as worse diastolic function compared to those with T1DM despite a similar

disease duration of 11.6 years [35]. The study also noted that those with T2DM had a worse cardiovascular risk profile and were more sedentary.

According to the TODAY2 long-term follow-up study, after only 13.3 years, at an average young age of 26.4 years, the incidence of severe cardiovascular-related events among the TODAY cohort was 3.71 per 1000 person-years [20••]. Seventeen serious cardiovascular events were reported among the 500 participants (four myocardial infarctions, six congestive heart failure, three coronary artery disease, and four stokes) and one death due to myocardial infarction. This data emphasizes the early onset of cardiovascular disease in this young population.

Treatment

Management of youth-onset T2DM starts with lifestyle intervention and pharmacologic management [33]. Youth with T2DM should be part of a lifestyle program that is developmentally and culturally appropriate with the goal of achieving 7–10% decrease in weight through healthy eating changes and participation in vigorous physical activity 30–60 min a day at least 5 days a week [33]. Addressing obesity in youth is associated with improved HbA1C [37]. In a recent study of youth with T2DM, weight reduction correlated with a reduction in HbA1C 1 year after diagnosis in patients prescribed metformin and those with insulin-containing regimens [38].

Biguanides and Insulin

Current pharmacologic management of T2DM in youth includes metformin +/− insulin +/− glucagon-like peptide 1 receptor agonist (GLP-1RA), depending on initial presentation and HbA1C [33]. Metformin is the preferred initial therapy for those diagnosed incidentally and metabolically stable (A1c < 8.5%), starting at a dose of 500–1000 mg/day and gradually increasing to 2000 mg daily [33]. Patients with marked hyperglycemia, A1C ≥ 8.5%, or ketosis should be started on basal insulin and metformin. The most recent ADA guidelines recommend the consideration of GLP-1RA if glycemic targets are not met with metformin monotherapy (with or without insulin) in children ≥ 10 years of age [33]. Patients with hyperglycemia despite taking a combination of basal insulin, metformin, and GLP-1RA therapies should have short-acting insulin with meals added to their regimen [33].

Glucagon-Like Peptide 1 Receptor Agonists

Until recently, metformin and insulin were the only pharmacological options available for youth with T2DM. In 2019, the FDA approved a GLP-1RA, liraglutide, for use in children ≥ 10 years of age and adolescents with T2DM. The ELLIPSE trial evaluated the efficacy and safety of liraglutide in youth aged 10–17 years with T2DM and found a reduction of 0.64% in HbA1C in the liraglutide group compared to a 0.42% increase in HbA1C in the placebo group after 26 weeks of therapy. It was also noted that 63.7% of patients in the liraglutide group achieved HbA1C values < 7.0%, while only 36.5% of the patients in the placebo group reached this endpoint [39]. In 2022, the AWARDS-PEDS investigators determined dulaglutide, a once-weekly GLP-1RA, also effectively improved glycemic control in youth aged 10–17 years with T2DM, reducing HbA1c 0.9 percentage points (with 1.5-mg dose) compared to an increase in 0.6 percentage points in the placebo group. In adults, both liraglutide and dulaglutide are associated with lower rates of cardiovascular disease and diabetic kidney disease [40]. Given previously stated data regarding severe complications in youth-onset T2DM, it is vital to consider early utilization of GLP-1 agonists as treatment.

Sodium-Glucose Co-transporter 2 Inhibitors

Sodium-glucose co-transporter 2 inhibitors (SGLT2i) are a class of glucose-lowering medications widely available for adults with T2DM that are not yet approved for use in children. Phase 3 results of a trial of dapagliflozin in children and young adults with type 2 diabetes determined that dapagliflozin safely lowers glucose in this population and represents a potential future treatment option for youth-onset T2DM [41]. A separate study of SGLT2i use in youth with T2DM, DINAMO: Diabetes study of liNAgliptin and eMpagliflozin in children and adOlescents (NCT03429543), is ongoing. Preliminary data of a phase 3 trial showed a statistically significant reduction in the primary outcome of HbA1C with empagliflozin compared to placebo in youth with T2DM, and safety data was similar to adults.

Metabolic Surgery

Metabolic bariatric surgery may be considered as a treatment option for adolescents with type 2 diabetes who have severe obesity (BMI > 35 kg/m^2) and poor glycemic control despite lifestyle and pharmacologic interventions [33]. Bariatric surgery is the most effective treatment of T2DM in adults, leading to remission of T2DM in as many as 30% of patients after 15 years [42, 43]. Bariatric surgery has been shown to lead to substantial and durable weight reduction and cardiometabolic benefits in adolescents as well [44]. In adolescents with T2DM, bariatric surgery is associated with improved glycemic control [45]. According to a secondary analysis of 30 youth with T2DM from the Teen-Longitudinal Assessment of Bariatric Surgery (Teen-LABs) study who

underwent bariatric surgery (of these, 24 underwent Roux-en-Y gastric bypass and 6 underwent sleeve gastrectomy), mean HbA1C improved from 6.8 to 5.5% two years after bariatric surgery. In a separate study of 263 youth with obesity and T2DM, 71.5% had remission of diabetes 7 years after sleeve gastrectomy [46].

Barriers Impacting Therapeutic Approach

As mentioned before, youth-onset T2DM disproportionally affects youth from racial/ethnic minorities and youth from households with lower self-reported income and a higher percentage of public health insurance. These socioeconomic factors, along with other factors such as major stress exposure, impact the consistent implementation of culturally sensitive lifestyle changes and medication adherence [47]. The TODAY study shows a strong association between major stress event exposure and poorer treatment adherence. The odds of treatment nonadherence were 58% higher in those reporting ≥ 1 major stressor than those without major stressors; the odds increased to 70% for those with ≥ 4 events [48].

Youth from disadvantaged backgrounds are adversely impacted by greater difficulty accessing safe and affordable exercise options and affordable healthy food. In addition, there may be more limited access to medication options and diabetes technology, such as continuous glucose monitoring and insulin pump therapy, due to high cost or lack of coverage by insurance.

Although there is a need for more data regarding specific barriers to adequate medication adherence in youth with type 2 diabetes, recent analyses from TODAY shed light on some of these barriers. In one analysis, depressive symptoms were more prevalent in youth with T2DM with lower medication adherence [49]. In a second analysis, youth with T2DM recalled several additional barriers to medication adherence, including forgetting to take medication when there were meal, sleep, or schedule disruptions [50]. There was a significant relationship between the total number of barriers reported and the degree of medication adherence [50]. The continued understanding and identification of these barriers are crucial for implementing comprehensive medical care for youth with type 2 diabetes.

The Socioeconomic Burden of Youth-Onset Diabetes

Before the COVID pandemic, the cost of diabetes in the USA in 2017 was $327 billion, with $237 billion attributed to direct medical costs and $90 billion in reduced productivity [51]. This cost accounted for 1 in 4 healthcare dollars spent in the USA. Globally, the economic burden of T2DM in adults aged 20–79 years old is predicted to increase from $1.3 trillion in 2015 to $2.1 trillion by 2030, taking into account an increased prevalence of diabetes among adults, from 415 million in 2015 (1 in 11 adults) to 642 million in 2040 (1 in 10 adults) [52].

Direct medical costs are 2.3 times higher for people with diabetes than those without diabetes [51]. Adults with diabetes have more frequent outpatient visits, ER visits, and hospitalizations than people without diabetes. In 2010, people with diabetes were 2.6 times more likely to be hospitalized in the past year than people without diabetes (21% versus 8%) [53]. Having complications of diabetes is associated with hospitalization. Indirect medical costs such as absenteeism, reduced productivity while working, reduced productivity for those not in the labor force, inability to work because of disease-related disability, and loss of productivity due to premature deaths are other significant contributors to the cost of diabetes.

While the economic burden of diabetes in adults has been well-described, the financial burden of youth-onset T2DM is unknown. Suppose the above analyses of the burden of diabetes in adults were extrapolated to include youth-onset T2DM. In that case, we hypothesize a significant increase in direct medical cost, accounting for the increased prevalence and earlier development of diabetes complications, including retinopathy, kidney failure, and cardiovascular disease in mid-life. Furthermore, we predict higher drug costs, given the longer duration of the disease across the lifespan and earlier need for multiple agents due to greater insulin resistance and more rapid beta-cell failure in youth. These direct costs would have a disproportionate burden on government-funded health care in the USA, as the majority of youth with T2DM have public insurance.

We propose that youth-onset T2DM contributes to additional unique indirect costs not seen in the adult population. It is known that among those with childhood-onset T1DM, children with diabetes miss more school than healthy children [54]. Furthermore, poor metabolic control was associated with underachievement. According to a national register of the Swedish population, T1DM hurts school grades, especially in those diagnosed between the ages of 10 and 15 years old, the period during which T2DM is often diagnosed in children [55]. The negative effect on school grades was worse in children whose mothers had a high-school degree versus a college degree. A separate study of the Swedish registry of socioeconomic data found that childhood onset of T1DM prior to 15 years of age is associated with worse labor market outcomes [56]. A chronic disease in childhood is known to cause reduced quality of life (QoL), with those from lower socio-economic backgrounds experiencing further reduced QoL compared with wealthier children [57]. Additionally, parents of children with chronic illness report decreased physiological and physical QoL relative to parents of children without illness [58].

Conclusions

The incidence and prevalence of youth-onset T2DM are increasing, especially among the youth of racial and ethnic minorities, and among those from families with lower socioeconomic status [1, 5]. This disease is projected to become much more prevalent over the next 40 years, and the gap in disparity of the disease is expected to widen [12••]. Youth-onset T2DM has a more severe metabolic phenotype than adult-onset T2DM, and treatment options for youth with T2DM are more limited [17, 18]. Together, these factors contribute to the earlier and more severe appearance of diabetes-related complications [20••].

While the economic cost of youth-onset T2DM has not been studied to date, given the rise in youth-onset T2DM and its severe, adverse clinical implications, we propose that youth-onset T2DM has a higher socioeconomic burden than both adult-onset T2DM and youth-onset T1DM. Given this, it is essential and urgent to prevent T2DM in youth. Further research needs to be performed to understand which environmental, lifestyle, and pharmacologic interventions most effectively reduce the onset of T2DM in childhood. Systemic initiatives to reduce major modifiable risk factors including reducing obesity and increasing physical activity, especially among high-risk disadvantaged populations, are also necessary through culturally appropriate lifestyle interventions. In addition to addressing the obesity epidemic, it is imperative to prevent diabetes in women of child-bearing age, before conception, to stop the cycle of detrimental epigenetic effects causing adverse metabolic effects in offspring of women with gestational diabetes.

In addition to prevention, it is essential to ensure adequate screening of T2DM in childhood and employ effective treatment once the diagnosis is established. The American Academy of Pediatrics and American Diabetes Association recommends screening for type 2 diabetes in all children age 10 years and older (as at the start of puberty) who are overweight or obese and have at least one risk factor for diabetes. Risk factors for type 2 diabetes include maternal history of diabetes during the child's gestation; family history of type 2 diabetes in a first or second degree relative; African American, Latino, Asian American, American Indian, or Pacific Islander race or ethnicity; and signs of insulin resistance or conditions associated with insulin resistance including acanthosis nigricans, polycystic ovarian syndrome, hyperglycemia, dyslipidemia, or history of small-for-gestational-age birth weight [59]. As more treatment options are emerging for youth with T2DM, there is also an urgent need to identify barriers to appropriate care, such as medication adherence in this vulnerable population. This is particularly important given recent data regarding the earlier appearance and severity of microvascular and macrovascular complications [20••].

Declarations

Conflict of Interest The authors declare no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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