BMJ Open Diabetes Research & Care

# Medical expenditure trajectory and HbA1c progression prior to and after clinical diagnosis of type 2 diabetes in a commercially insured population in the USA

Lorissa Pagán ,[1] Wenya Yang,[1] Hui Shao,[2] Yu Wang,[3] Ping Zhang[3]

**To cite:** Pagán L, Yang W, Shao H, *et al*. Medical expenditure trajectory and HbA1c progression prior to and after clinical diagnosis of type 2 diabetes in a commercially insured population in the USA. *BMJ Open Diab Res Care* 2023;**11**:e003397. doi:10.1136/bmjdrc-2023-003397

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjdrc-2023-003397).

Received 6 March 2023
Accepted 8 September 2023



[1]The Lewin Group, Falls Church, Virginia, USA
[2]Department of Pharmaceutical Outcomes and Policy, University of Florida College of Pharmacy, Gainesville, Florida, USA
[3]Division of Diabetes Translation, Centers for Disease Control and Prevention, Atlanta, Georgia, USA

**Correspondence to**
Dr. Lorissa Pagán;
lorissa.pagan@lewin.com

## ABSTRACT

**Introduction** Medical expenditures of individuals with type 2 diabetes escalate before clinical diagnosis. How increases in medical expenditures are related to glucose levels remains unclear. We examined changes in HbA1c and medical expenditures in years prior to and shortly after type 2 diabetes diagnosis.

**Research design and methods** Using insurance claims and laboratory test results from a commercially insured population in the USA, we built three (2014, 2015, 2016) longitudinal cohorts with type 2 diabetes up to 10 years before and 2 years after the diagnosis (index year). We identified diabetes diagnosis using International Classification of Diseases, Ninth Revision and Tenth Revision codes and antidiabetic medication use. We ran two individual fixed regression models with annual total medical expenditures and average HbA1c values as dependent variables and number of years from diagnosis as the main independent variable and examined the risk-adjusted movement of the outcomes.

**Results** Our study included 9847 individuals (83 526 person-years). Medical expenditures and HbA1c levels increased before and peaked at the diagnosis year. Medical expenditures were $8644 lower 10 years and $5781 lower 1 year before diagnosis compared with the index year. HbA1c was 12.18 mmol/mol (1.11 percentage points) and 3.49 mmol/mol (0.32 percentage points) lower, respectively. Average annual increases in medical expenditures and HbA1c values over the prediagnosis period were $318 and 0.97 mmol/mol (0.09 percentage points), respectively.

**Conclusions** Medical expenditures and HbA1c values followed similar trajectories before and after diabetes diagnosis. Our results can inform economic evaluations of programs and policies aimed at preventing type 2 diabetes.

### WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Medical expenditures are higher for individuals prior to and after the initial type 2 diabetes diagnosis compared with those who do not develop diabetes. The changes in both expenditures and glucose levels in years prior to type 2 diabetes diagnosis have not been clearly described.

### WHAT THIS STUDY ADDS

⇒ We examined the risk-adjusted movement total medical expenditures and HbA1c prior to and immediately after diagnosis of type 2 diabetes. We found that both average HbA1c and total medical expenditures follow a similar trajectory before and after diagnosis. The average annual increases in medical expenditures and HbA1c values over the 10-year prediagnosis period were $318 and 0.97 mmol/mol (0.09 percentage points), respectively.

### HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our results provide information for economic evaluations of programs and policies aimed at preventing type 2 diabetes.

## INTRODUCTION

Medical expenditures are higher for individuals in years leading up to and after the initial type 2 diabetes diagnosis, compared with expenditures for those who do not develop diabetes.[1–5] HbA1c values among these individuals are also higher in those years, compared with those who do not develop diabetes, as HbA1c values among patients with pre-diabetes increase over time to reach the threshold of type 2 diabetes.[6] How medical expenditures and HbA1c values are related in years prior to type 2 diabetes diagnosis has not been clearly described in the literature. Understanding this relationship could have important implications for type 2 diabetes prevention. Lifestyle intervention has been shown to be effective in slowing the progression of type 2 diabetes among those with a high risk of developing type 2 diabetes.[7 8] However, the assessment of financial benefits resulting from lifestyle intervention programs depends on a clear understanding of the relationship between medical expenditures and

HbA1c values among high-risk individuals. If changes in HbA1c values are positively associated with the change in medical expenditures during the years prior to the diabetes diagnosis, delaying the onset of diabetes through reducing HbA1c levels before diabetes diagnosis may result in reductions in medical spending.

The objective of this study is to assess movement in HbA1c and medical expenditures prior to and immediately after diabetes diagnosis among individuals with diagnosed type 2 diabetes. We hypothesized that changes in HbA1c values are closely associated with changes in medical expenditures in years before the diabetes diagnosis and that both outcomes would move similarly over time.

## RESEARCH DESIGN AND METHODS

### Data source

We used data from the Optum deidentified Normative Health Information (dNHI) database, a longitudinal claims research database for privately insured individuals, containing eligibility, medical, and pharmacy claims data from a large US health plan. For roughly one-third of the dNHI covered population, or approximately 7–8 million individuals per year, independent laboratory results are available, which made it possible to examine the changes in average HbA1c values over time for a subsample of person-years.

### Identification of pre-diabetes cohort

Our study sample included individuals newly diagnosed with type 2 diabetes in 2014, 2015, or 2016 (the 'diagnosis year' or 'index year'). We considered an individual to have a type 2 diabetes if they met either of the following conditions in the diagnosis year: (1) the individual had at least one claim in inpatient records or a minimum of two claims in outpatient records where the outpatient claims were at least 30 days apart (the second outpatient claim could be in the following year) in which there was indication of having type 2 diabetes by International Classification of Diseases, Ninth Revision and Tenth Revision (ICD-9 and ICD-10) diagnosis codes (specific codes of ICD-9 diagnosis code 250 and ICD-10 diagnosis codes E11 and E13; see online supplemental table S1), or (2) the drug claims indicated that the individual filled an antidiabetic drug (eg, insulin, biguanides, glucagon-like peptide-1, sodium-glucose transport protein 2 inhibitors, sulfonylureas, meglitinide, thiazolidinedione, dipeptidyl peptidase 4 inhibitors; excluding monotherapy metformin). We also required that the individuals have continuous prescription and medical coverage for 2 years before and at least 1 year after the diagnosis year, resulting in continuous medical and prescription coverage for a minimum of 4 years. We examined a maximum of 10 years of data before diagnosis and up to 2 years of data after diagnosis, conditional on the individual maintaining continuous coverage during the timeframe. Because we were interested in changes in both the medical expenditures and HbA1c values over time, we required that individuals have results in our data for at least one HbA1c test during the prediagnosis period.

To ensure the selected patients with type 2 diabetes were newly diagnosed, we then restricted the sample to individuals with no claims-based evidence of type 2 diabetes in the years leading up to diagnosis, where claims with ICD-9 or 10 diagnosis codes for type 2 diabetes or a prescription refill for antidiabetic drugs (excluding metformin) during the preperiod was considered evidence of a prior diagnosis. After identifying individuals newly diagnosed with type 2 diabetes, we also excluded individuals with evidence of type 1 diabetes, gestational diabetes during pregnancy, drug-induced diabetes, or secondary diabetes in any of the study years based on ICD-9 or 10 codes. Individuals with undiagnosed diabetes may have higher costs than a truly pre-diabetes sample, thus we excluded individuals from the sample that had either two HbA1c tests in 1 year during the preperiod with values greater than 46.45 mmol/mol (6.4%) or individuals that had a single test with an HbA1c value greater than 51.91 mmol/mol (6.9%) anytime during the preperiod. Additionally, we excluded individuals who were 65 or older during the 4-year required coverage period as persons aged ≥65 years in the USA are mostly covered by the Medicare program and are likely to have incomplete data in our dataset for the privately insured. Finally, we excluded individuals with a heart or liver transplant during the study period. See online supplemental figure S1 for a flow chart applying the inclusion and exclusion criteria and online supplemental table S1 for a list of ICD-9 and 10 codes used in our inclusion and exclusion criteria.

We constructed a longitudinal dataset at the person-year level, which included up to 13 years of data for each individual with type 2 diabetes. Online supplemental figure S2 shows the structure of each cohort in terms of the diagnosis year, the preperiod, and the postperiod and the corresponding calendar year.

### Statistical analyses

We calculated total medical expenditure (payments from the health plan, third party, and patient out-of-pocket) in 2020 US$ and average HbA1c values (mmol/mol) by year. We ran two separate regression models with annual total medical expenditures and average annual HbA1c values as the respective outcome variables. The model controlled for high-cost medical conditions and comorbidities identified by ICD-9 and 10 codes (, online supplemental table S2). The model also included an individual-level fixed-effect factor to control for both observable and unobservable time-invariant individual-level factors.

The main independent variables of interest were a set of indicators of the number of years before or after diagnosis. The coefficients on these time indicators measured the differential in the outcomes between the diagnosis year and each year before or after diagnosis, after controlling for other factors. These coefficients were used to compare incremental changes in medical expenditures and HbA1c values over time.

Both medical expenditures and HbA1c values may follow a different trajectory for individuals with obesity. As a secondary analysis, we ran the same regression models stratified by obesity status, that is, those with and without claims-based evidence of obesity identified by ICD-9 and 10 codes at any time during the study period.

To bridge the two sets of regression results, we calculated the predicted risk-adjusted medical expenditure and predicted risk-adjusted HbA1c value based on the estimated differential between the year of diagnosis and a given year (time indicator coefficient) and the sample average of the outcome during the year of diagnosis. For example, to calculate the prediction of HbA1c 1 year prior to diagnosis, we added the sample average of HbA1c values during the year of diagnosis and the coefficient on the time indicator for 1 year prior to diagnosis. After constructing these predictions for medical spending and average HbA1c values, we plotted the values corresponding to each year to visualize the relationship. We also calculated the average yearly incremental change in the outcomes by calculating the differences in the coefficient estimates year over year and taking the average of those differences in the years leading up to diagnosis.

For individuals with 10 or more years of continuous coverage before the diabetes diagnosis, we could observe both HbA1c values and medical expenditures during the entire prediagnosis period. In comparison, for individuals with less than 10 years of continuous coverage prior to diagnosis, we could only observe these values for some of the 10-year prediagnosis period. We conducted a sensitivity analysis to assess the implications of the potential bias from including individuals with different look-back periods by running both the total medical expenditures and average annual HbA1c regressions for only individuals with at least 10 years of continuous prediagnosis coverage. Additionally, we assessed the robustness of our results to the exclusion of individuals with undiagnosed diabetes by estimating the regressions without excluding individuals with high HbA1c values during the preperiod.

We also calculated unadjusted expenditure trends by spending category (ie, inpatient facility care, outpatient facility care, pharmacy, office visits, laboratory, and other). This information can help identify expenditure patterns associated with progressions to and diagnosis of type 2 diabetes for each spending category and to explain the trend of the total medical expenditure.

## Data and resource availability

The data that support the findings of this study are available from Optum, but restrictions apply to the use of these data, which were analyzed under license for the current study and therefore are not publicly available. Aggregated results based on the data are available from the authors on reasonable request and with permission of Optum.

**Table 1** Sample characteristics of individuals

| Variable | n (9847) | % or mean (SD) |
|---|---|---|
| Number of years in sample | | |
| 4 | 446 | 4.5% |
| 5 | 1595 | 16.2% |
| 6 | 1247 | 12.7% |
| 7 | 1094 | 11.1% |
| 8 | 870 | 8.8% |
| 9 | 858 | 8.7% |
| 10 | 665 | 6.8% |
| 11 | 770 | 7.8% |
| 12 | 880 | 8.9% |
| 13 | 1422 | 14.4% |
| Demographics during diagnosis year | | |
| Age | 9847 | 51.1 (8.7) |
| Female | 5169 | 52.5% |
| Asian | 583 | 5.9% |
| Black (non-Hispanic) | 835 | 8.5% |
| Hispanic | 1584 | 16.1% |
| Unknown race | 1505 | 15.3% |
| White (non-Hispanic) | 5340 | 54.2% |
| Those with high-cost conditions during index year | | |
| Cancer | 1307 | 13.3% |
| HIV/AIDS | 60 | 0.6% |
| Childbirth | 157 | 1.6% |
| Those with comorbidities during index year | | |
| Hypertension | 6308 | 64.1% |
| Hyperlipidemia | 6951 | 70.6% |
| Chronic obstructive pulmonary disease | 449 | 4.6% |
| Dementia | 45 | 0.5% |
| Paralysis | 33 | 0.3% |
| Liver disease | 1123 | 11.4% |
| Ulcers | 174 | 1.8% |
| Rheumatoid disease | 221 | 2.2% |
| Morbid obesity | 1493 | 15.2% |

Sex, race, and ethnicity statistics are based on categories available in the deidentified Normative Health Information (dNHI) database. Individuals with missing values for race and ethnicity have been included in the unknown race category.

## RESULTS

The final sample included 9847 individuals with a total of 83 526 person-year observations in the analytical dataset, with approximately 9.1% of the individuals having inpatient claims with a diabetes diagnosis during the index year. Table 1 shows descriptive statistics of the study population. By construction, individuals had at least 4 years

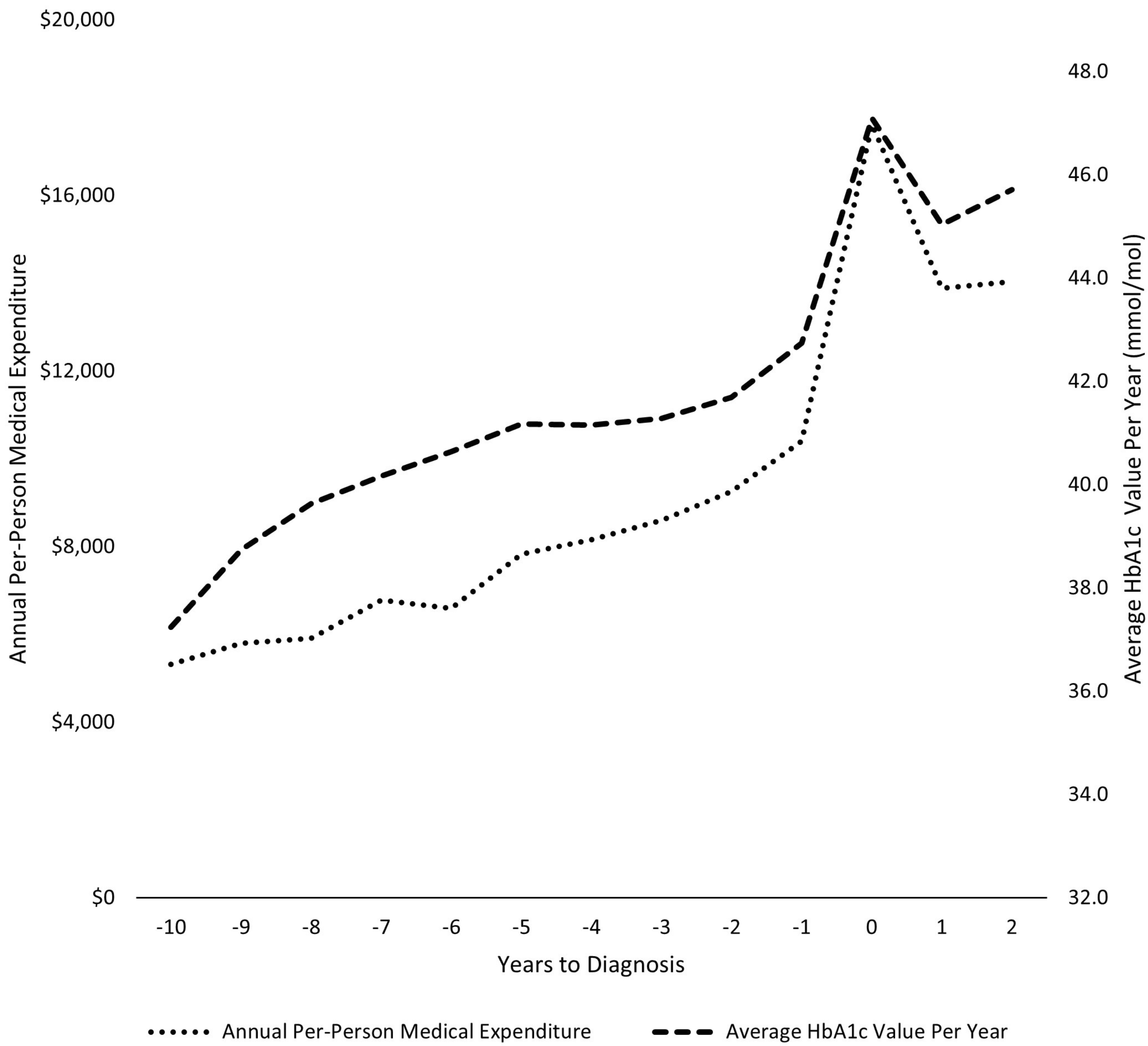


**Figure 1** Average medical spending and HbA1c values by year before and after type 2 diabetes diagnosis. This figure shows the unadjusted averages of per-person annual medical expenditure (dotted line) and average HbA1c values (long dashes) during each year 10 years before and 2 years after a diagnosis of type 2 diabetes. Note that HbA1c test results are only available for a subsample of person-years (34 533 out of 83 526 person-years, or 41%). Both medical spending and HbA1c follow a similar trajectory over time.

of continuous coverage. On average, individuals contributed 8.5 years of data, and over 14% had a full 13 years of data. The mean age at diagnosis was 51.1 years. A majority of individuals had hypertension or hyperlipidemia (64% and over 70%, respectively) and slightly over 15% of the sample had morbid obesity during the diagnosis year.

Figure 1 shows the unadjusted observed average annual expenditures (in 2020 US$) and average HbA1c values by the number of years before and after diagnosis. Both outcomes followed a similar trajectory of a slow but steady increase before diabetes diagnosis, a peak in the diagnosis year, and a quick fall after the diagnosis year.

Results on unadjusted trends by expenditure category show that there was a slow and steady increase in spending across categories during the prediagnosis period, with outpatient and pharmacy expenditures being the largest of the groupings (online supplemental figure S3). During the year of diagnosis, there was a notable increase in most categories, with the increase in inpatient facility expenditures accounting for roughly one-half of the increase in total expenditures. Among individuals with non-zero inpatient facility expenditures during the index year (n=1198), 46.2% of the expenditures were related to diabetes on average, as identified through the presence of diagnosis codes. During the years following diagnosis, most categories experienced a decline in expenditures relative to the diagnosis year. One exception was pharmacy

**Table 2** Annual medical expenditure (2020 US$) and average HbA1c values before and after the diagnosis of type 2 diabetes estimated from the panel linear regression with fixed effects

| | Total medical expenditure, 2020 US$ (n=83 526) | | | Average HbA1c, mmol/mol (n=34 533) | | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **SE** | **P value** | **Coefficient** | **SE** | **P value** |
| Time | | | | | | |
| −10 | −$8644 | $674 | <0.0001 | −12.18 | 1.17 | <0.0001 |
| −9 | −$8509 | $584 | <0.0001 | −7.64 | 0.98 | <0.0001 |
| −8 | −$8461 | $524 | <0.0001 | −8.51 | 0.65 | <0.0001 |
| −7 | −$7745 | $483 | <0.0001 | −7.74 | 0.49 | <0.0001 |
| −6 | −$8027 | $449 | <0.0001 | −7.06 | 0.36 | <0.0001 |
| −5 | −$7027 | $421 | <0.0001 | −6.63 | 0.29 | <0.0001 |
| −4 | −$7061 | $396 | <0.0001 | −6.13 | 0.23 | <0.0001 |
| −3 | −$6696 | $372 | <0.0001 | −5.73 | 0.18 | <0.0001 |
| −2 | −$6419 | $350 | <0.0001 | −4.88 | 0.15 | <0.0001 |
| −1 | −$5781 | $348 | <0.0001 | −3.49 | 0.13 | <0.0001 |
| 0 | | | | | | |
| 1 | −$3160 | $345 | <0.0001 | −2.00 | 0.12 | <0.0001 |
| 2 | −$2491 | $374 | <0.0001 | −1.61 | 0.14 | <0.0001 |
| High cost | | | | | | |
| Cancer | $9146 | $346 | <0.0001 | −0.15 | 0.16 | 0.3781 |
| HIV/AIDS | $6257 | $3418 | 0.0672 | −0.66 | 1.60 | 0.6803 |
| Childbirth | $15 797 | $1147 | <0.0001 | −2.78 | 0.64 | <0.0001 |
| Comorbidities | | | | | | |
| Hypertension | $6065 | $276 | <0.0001 | −0.14 | 0.15 | 0.3408 |
| Hyperlipidemia | $579 | $244 | 0.0179 | −0.11 | 0.13 | 0.4095 |
| Chronic obstructive pulmonary disease | $6834 | $535 | <0.0001 | −0.20 | 0.27 | 0.4705 |
| Dementia | $33 724 | $1813 | <0.0001 | −1.23 | 0.84 | 0.1429 |
| Paralysis | $55 342 | $2286 | <0.0001 | −0.36 | 1.05 | 0.7342 |
| Liver disease | $4106 | $335 | <0.0001 | −0.14 | 0.16 | 0.3909 |
| Ulcers | $14 085 | $939 | <0.0001 | −0.34 | 0.37 | 0.3586 |
| Rheumatoid disease | $11 105 | $934 | <0.0001 | −0.63 | 0.42 | 0.1373 |
| Unadjusted mean outcome during index year | $17 615 | | | 47.1 mmol/mol | | |

Coefficients in the total medical expenditure regression are in 2020 dollars. Coefficients in average HbA1c regression are in mmol/mol. The HbA1c sample includes person-years where an individual has at least one HbA1c test value during the year and is a subsample of the total medical expenditure sample.

expenditures, which continued to gradually increase after diagnosis.

The estimated coefficients from the total medical expenditures and average annual HbA1c regression models, controlling for comorbidities and individual fixed effects, are shown in table 2. The negative coefficients on time indicators from the expenditure model indicated that medical spending was lower in years before and after a type 2 diabetes diagnosis compared with the diagnosis year. Overall, medical spending increased over time in the prediagnosis period. During the diagnosis year, the unadjusted average total medical expenditure was $17 615. Ten years before the diagnosis of diabetes, spending was $8644 lower than during the diagnosis year, while the year before diagnosis medical spending was $5781 lower than during the diagnosis year, after controlling for other factors. Following diagnosis, the average per-person medical expenditure was lower than during the diagnosis year, though the time indicator coefficients were smaller in magnitude than the prediagnosis coefficients, even compared with the year before diagnosis, indicating that medical spending was higher after diagnosis than before diagnosis.

HbA1c regression was conducted only among a subset of the study sample (34 533 out of 83 526 person-years, or approximately 41% of the total sample) as not all individuals had an HbA1c test every year during the study period (see, online supplemental table S2 for counts of individuals with at least one HbA1c value in each year). Similar to the annual medical expenditures, HbA1c values were lower during the prediagnosis and postdiagnosis periods compared with the year of diagnosis, as indicated by the negative coefficients on the time indicators (table 2). Overall, HbA1c values increased over time leading to diagnosis, with an incremental increase of 4.54 mmol/mol (0.42 percentage points) going from 10 to 9 years before diagnosis, decreasing slightly between 9 and 8 years before diagnosis, and then mostly steadily increasing (indicated by the coefficients becoming less negative) as the individual approached the diagnosis year. By 1 year before diagnosis, HbA1c values were about 3.49 mmol/mol (0.32 percentage points) lower than during the year of diagnosis. HbA1c values were also lower in the postdiagnosis period than during the diagnosis year, though the average HbA1c values remained higher (closer to the diagnosis year value) during the postdiagnosis period than the prediagnosis period. The estimated average yearly incremental change before the type 2 diabetes diagnosis was $318 for total expenditures and 0.97 mmol/mol (0.09 percentage points) for HbA1c value.

Figure 2 shows the predicted average medical expenditures and predicted average HbA1c by year. A visual inspection of the plot indicated that there may be a positive relationship between the two outcomes.

Unadjusted average medical expenditures in the diagnosis year for individuals with obesity were higher than those without obesity, and the coefficients on the time indicators from the medical expenditure regressions were somewhat larger for the subgroup with obesity during the prediagnosis period (see online supplemental tables S3 and S4). For the HbA1c regressions, the coefficient estimates on the time indicators were generally also larger for individuals in the obesity subgroup, though the size of the difference attenuated in later years of the prediagnosis period. Despite these differences, the coefficients on the time indicators generally followed a similar pattern to each other and the main results. The estimated coefficients were also similar for both outcomes between those with a complete 10 years of preperiod data as well as when we included individuals with undiagnosed

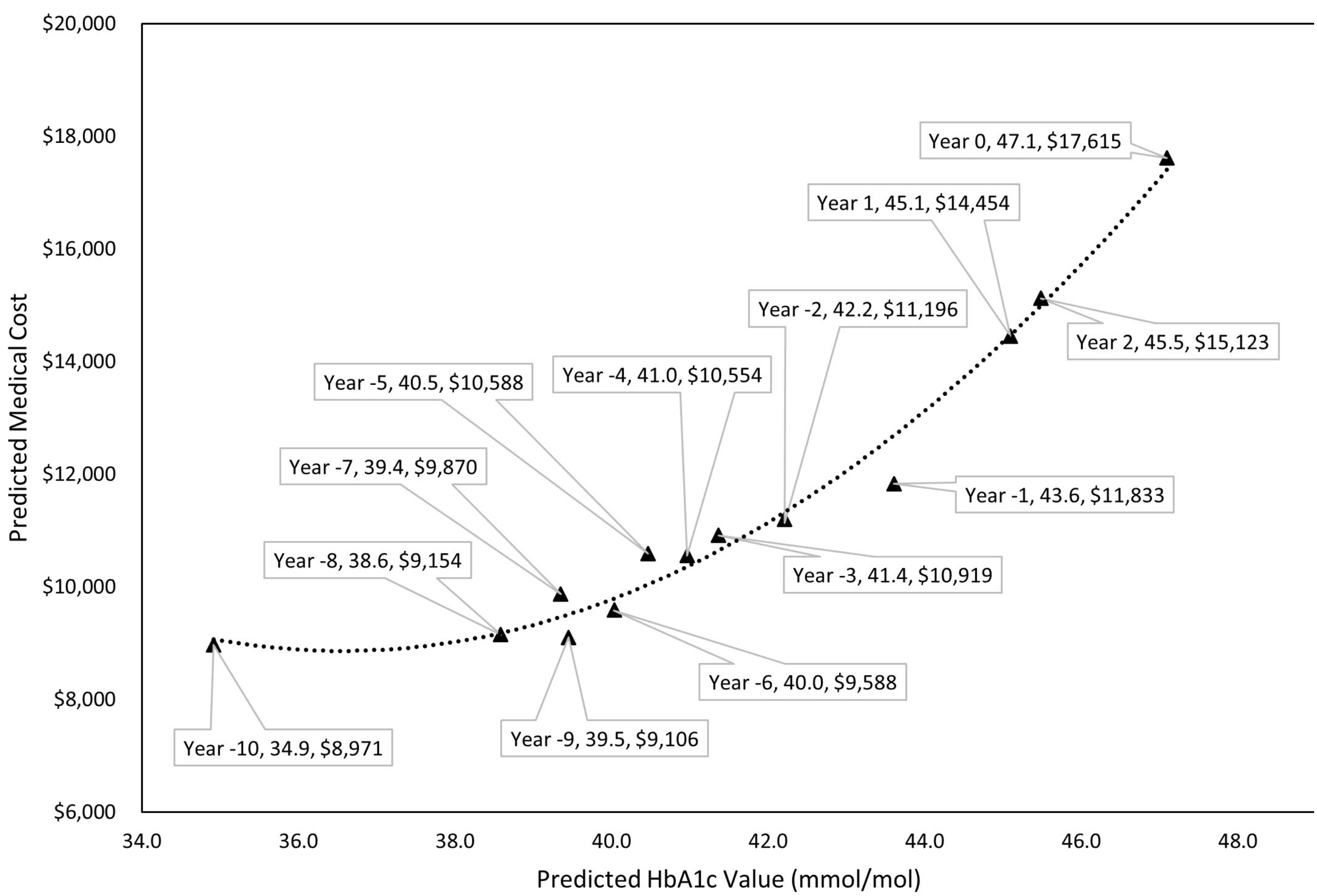


**Figure 2** Predicted medical expenditures and HbA1c values before and after diabetes diagnosis. This figure shows the plot of combinations of predicted annual medical expenditures and predicted HbA1c values in each year, where year -10 indicates 10 years prior to diagnosis, year 0 is the diagnosis year, and year 2 is 2 years after diagnosis. We have fit a line through the points to help illustrate the relationship (dotted line).

diabetes in the sample (see online supplemental tables S5 and S6).

## CONCLUSIONS

We aimed to assess changes in medical expenditures and during the progression to type 2 diabetes as measured by HbA1c prior to diagnosis. We found a similar trajectory in medical expenditures and HbA1c values over time, increasing in the years leading up to diagnosis, peaking at the diagnosis year, and falling in the years following diagnosis, both when examining the unadjusted trends and the estimated coefficients after adjusting for other factors. The estimated average increase over the 10-year period prior to type 2 diabetes diagnosis was about $300 per year for medical expenditures and 0.97 mmol/mol (0.09 percentage points) for HbA1c. Although not implying a causal relationship, visual inspection indicated a potentially positive association between HbA1c level and medical expenditures. If there is a positive relationship, then slowing the progression to type 2 diabetes may slow the increase in medical expenditures during the years leading to the diagnosis of type 2 diabetes.

While there is extensive literature on changes in spending after a diagnosis of diabetes, few studies have examined changes in spending in the years before diagnosis. Findings from those studies indicated that medical expenditures begin to rise many years before a type 2 diagnosis and that the difference in medical expenditures between individuals with and without diabetes becomes wider as an individual approaches diabetes diagnosis.[4] For example, Shrestha and colleagues assessed the incremental medical expenditures for adults with newly diagnosed type 2 diabetes before and after diagnosis.[5] The study demonstrated that individuals diagnosed with type 2 diabetes had higher medical expenditures compared with matched controls who never developed diabetes, after diagnosis and up to 10 years prior to diagnosis.[5] Another more recent study found that incremental costs began to rise in patients with diabetes at least 5 years before diagnosis and accelerated in the year of diagnosis. The study compared newly diagnosed patients to control patients without a diabetes diagnosis and found that patients with diabetes spent $8941 more over a 5-year time span (4 years before diagnosis and the year of diagnosis), with almost half of the additional cost occurring in the 4 years before diagnosis ($4113 of the $8941).[3] However, neither of these two studies was able to examine how medical expenditure changes were related to changes in glucose levels or to link changes in spending directly to changes in glucose level, mainly due to a lack of data on glucose measurements in their datasets.

The strengths of our paper are that we were able to calculate spending in each year using claims data rather than patient self-reports and have data on at least one HbA1c laboratory result for all individuals in our sample. Because of this, we can compare the trends in HbA1c and medical expenditures during the years leading up to a type 2 diabetes diagnosis and examine the movement of medical expenditures and HbA1c values longitudinally. The availability of the laboratory results on HbA1c value also allowed us to identify individuals with HbA1c tests in the diabetic range during the preperiod to remove individuals with undiagnosed diabetes from the sample.

Many interventions are effective in slowing the progression of type 2 diabetes among individuals who are at high risk of developing the disease.[8] Whether these interventions are cost-effective partially depends on if slowing the progression to type 2 diabetes can result in savings in medical expenditures. While our study cannot answer this question directly, our finding that increases in HbA1c values on average were concurrent with increases in medical expenditure during the prediabetes period among those later diagnosed with type 2 diabetes may imply that interventions that can slow the diabetes progression could have some economic benefit. The estimated changes in medical expenditure and HbA1c values could be used to inform financial benefits of preventing or delaying type 2 diabetes resulting from prevention programs, or simulation models that assess the cost-effectiveness of the diabetes prevention programs.

This study has several limitations. Laboratory HbA1c results were only available for a subgroup of our study population and the records were collected from two national independent laboratories. Individuals with at least one HbA1c test in the study sample may be different from individuals with unknown pre-diabetes that may not have received testing services, which may have led to an overestimate in the changes in medical expenditures and HbA1c progression and may limit the generalizability of our findings. Although we excluded individuals with high HbA1c test results during the prediagnosis period, there may still be patients with undiagnosed diabetes who are not identifiable in our data. For the subgroup analysis, we used ICD-9 and 10 codes to identify beneficiaries with evidence of obesity. However, it is possible some individuals with non-clinical obesity were misclassified as not having obesity. Additionally, the hypertension and hyperlipidemia comorbidities are highly correlated with high blood glucose levels and therefore we may have overcontrolled the estimation of the cost and HbA1c changes over time. Lastly, while our analytical approach allows us to assess changes in the two outcomes over time and to visually compare the trends, we were not able to directly quantify the association as the regressions were estimated separately.

We described trajectory in medical expenditures and HbA1c prior to type 2 diabetes diagnosis by estimating both the changes in these two variables during the years prior to and shortly after the diabetes diagnosis. We observed similar trajectories in average HbA1c and medical spending over time, with and without adjusting for confounding factors. Our results could support economic evaluations of programs and policies aimed at preventing type 2 diabetes.

**Acknowledgements** The authors acknowledge Inna Cintina, PhD, and Matt Zhou, MS, for their contributions in the preparation of the analytical plan and database construction.

**Contributors** LP contributed to the design of the study, data construction and analysis, discussion, and write-up. WY contributed to the design of the study, analysis of data, discussion of results, and write-up. HS, YW, and PZ contributed to the design of the study, discussion, and write-up. LP is the guarantor of this work and, as such, had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

**Funding** Funding for this study was provided under contract from the Centers for Disease Control and Prevention (Contract No 75D30120P08898).

**Disclaimer** The contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention, the Department of Health and Human Services, or the US government. The manuscript was submitted for clearance by the Centers for Disease Control and Prevention prior to submission, which is required for manuscripts with authors from the agency.

**Competing interests** LP and WY are employees of the Lewin Group, which is owned by a subsidiary of the United Health Group and may own and/or hold stock options in the company. LP and WY provide paid consulting services to federal and state governments, non-profit entities, and for-profit entities. HS has received funding from the Centers for Disease Control and Prevention and the National Institute of Diabetes and Digestive and Kidney Diseases.

**Patient consent for publication** Not applicable.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data may be obtained from a third party and are not publicly available. The data that support the findings of this study are available from Optum, but restrictions apply to the use of these data, which were analyzed under license for the current study and therefore are not publicly available. Aggregated results based on the data are available from the authors upon reasonable request and with permission of Optum.



**ORCID iD**

Lorissa Pagán http://orcid.org/0000-0003-2150-5633

## REFERENCES

1 Dall T, Yang W, Gillespie K, *et al*. The economic burden of elevated blood glucose levels in 2017: diagnosed and undiagnosed diabetes. *GDM* 2019;42:1661–8.
2 Khan T, Tsipas S, Wozniak G. Medical care expenditures for individuals with prediabetes: the potential cost savings in reducing the risk of developing diabetes. *Popul Health Manag* 2017;20:389–96.
3 Khan T, Yang J, Wozniak G. Trends in medical expenditures prior to diabetes diagnosis: the early burden of diabetes. *Popul Health Manag* 2021;24:46–51.
4 Nichols GA, Glauber HS, Brown JB. Type 2 diabetes: incremental medical care costs during the 8 years preceding diagnosis. *Diabetes Care* 2000;23:1654–9.
5 Shrestha SS, Zhang P, Hora IA, *et al*. Trajectory of excess medical expenditures 10 years before and after diabetes diagnosis among U.S. adults aged 25–64 years, 2001–2013. *Diabetes Care* 2019;42:62–8.
6 Morris DH, Khunti K, Achana F, *et al*. Progression rates from hba1C 6.0-6.4% and other prediabetes definitions to type 2 diabetes: a meta-analysis. *Diabetologia* 2013;56:1489–93.
7 Diabetes prevention program research group. the 10-year cost-effectiveness of lifestyle intervention or metformin for diabetes prevention: an intent-to-treat analysis of the DPP/DPPOS [published correction appears in diabetes care Dec;36:4173-5]. *Diabetes Care* 2012:723–30.
8 Zhou X, Siegel KR, Ng BP, *et al*. Cost-effectiveness of diabetes prevention interventions targeting high-risk individuals and whole populations: a systematic review. *Diabetes Care* 2020;43:1593–616.