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Association of Potentially Modifiable Diabetes Care Factors With Glycemic Control in Patients With Insulin-Treated Type 2 Diabetes

Julie C. Lauffenburger, PharmD, PhD; Jennifer Lewey, MD, MPH; Saira Jan, MS, PharmD; Jessica Lee, BA; Roya Ghazinouri, DPT, MS; Niteesh K. Choudhry, MD, PhD

Abstract

IMPORTANCE Numerous factors are associated with the ability of patients with type 2 diabetes to achieve optimal glycemic control. However, many of these factors are not modifiable by quality improvement interventions. In contrast, the structure of how diabetes care is delivered, such as whether patients visit an endocrinologist or how prescriptions are filled, is potentially modifiable, yet its associations with glycemic control have not been rigorously evaluated.

OBJECTIVE To investigate the association of diabetes care delivery with glycemic control in patients with type 2 diabetes using insulin.

DESIGN, SETTING, AND PARTICIPANTS This retrospective cohort study used baseline claims and laboratory insurer data within a large pragmatic trial to identify individuals with type 2 diabetes using insulin with data for at least 1 hemoglobin A_{1c} (HbA_{1c}) test result from before trial randomization (July 1, 2014, to October 5, 2016) and for key nonmodifiable patient factors as well as diabetes care delivery and behavioral factors measured before the HbA_{1c} test. Analyses were conducted from February 4, 2017, to November 13, 2018.

MAIN OUTCOMES AND MEASURES Multivariable modified Poisson regression was used to evaluate the independent associations of nonmodifiable patient factors and potentially modifiable diabetes care delivery and patient behavioral factors with achieving adequate diabetes control (ie, HbA_{1c} level <8%). The extent of measured variation explained in glycemic control by these factors was also explored using pseudo R^2 and C statistics.

RESULTS Of 1423 patients included, 565 (39.7%) were women, and the mean (SD) age was 56.4 (9.0) years. In total, 690 (48.5%) had HbA_{1c} levels less than 8%. Age (relative risk [RR] per 1-unit increase, 1.01; 95% CI, 1.00-1.02), persistent use of basal insulin (RR, 1.20; 95% CI, 1.00-1.43), more frequent filling of glucose self-testing supplies (RR, 1.01; 95% CI, 1.01-1.02), visiting an endocrinologist (RR, 1.41; 95% CI, 1.19-1.67), and receipt of insulin prescriptions by mail order (RR, 1.23; 95% CI, 1.03-1.48) were all independently associated with adequate control. Measured potentially modifiable diabetes care factors explained more variation in adequate glycemic control than measured nonmodifiable patient factors (C statistic, 0.661 vs 0.598; pseudo R^2 = 0.11 vs 0.04).

CONCLUSIONS AND RELEVANCE These findings suggest that for patients with type 2 diabetes using insulin, the way in which care is delivered may be more strongly associated with achieving adequate control of HbA_{1c} levels than patient factors that cannot be altered are. Given the potential for intervention, these care delivery factors could be the focus of efforts to improve diabetes outcomes.

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Key Points

Question Are diabetes care delivery and patient behavioral factors differentially associated with adequate glycemic control in patients with insulin-treated type 2 diabetes compared with nonmodifiable patient factors?

Findings In this cohort study including 1423 patients, several diabetes care and patient behavioral factors, such as frequent filling of glucose self-testing supplies and visiting an endocrinologist, had stronger associations with achieving adequate glycemic control compared with measured nonmodifiable demographic and clinical patient factors. Among these potentially modifiable factors, the most notable appeared to be the nature of patients' interactions in the health care system.

Meaning These findings suggest that given their potential to be modified, future efforts could focus on diabetes care delivery factors as points for quality improvement interventions to improve diabetes outcomes.

+ Supplemental content

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Introduction

Recent advancements in treatments for type 2 diabetes have created new opportunities to better manage this highly prevalent chronic condition.[1] Poor glycemic control can lead to avoidable adverse events, including macrovascular and microvascular complications, hospitalizations, and even death.[2,3] To achieve optimal glycemic control, health care must be delivered in ways that help patients to manage multiple aspects of their care, including adherence to treatment, lifestyle modifications, and regular monitoring.[4] This is particularly true for patients using insulin, who face unique challenges in maintaining glycemic control because of the added requirements of regular blood glucose testing, monitoring, and other perceived burdens of insulin administration.[5,6]

Numerous factors have been found to be associated with the ability of patients with type 2 diabetes to achieve glycemic control, including age, sex, or comorbid conditions.[2,5,6] However, many of these characteristics are not modifiable and thus cannot be addressed by efforts to improve diabetes outcomes.[7-10] In contrast, the structure of how diabetes care is delivered, such as whether patients are treated by an endocrinologist or how prescriptions are filled, are potentially modifiable. However, the association of these care delivery and patient behavior factors with diabetes control compared with nonmodifiable patient factors is not well described, particularly among patients with type 2 diabetes using basal insulin.[3,9,11]

Therefore, the goal of this study was to examine the association of diabetes care delivery and patient behavior with adequate glycemic control in patients with type 2 diabetes using insulin. Exploring the potential relative strength of associations of these factors with glycemic control compared with patient demographic or clinical factors could improve the ability to develop and target interventions for this highly relevant patient population, particularly from the lens of a health care organization using population-level data.

Methods

This study was approved by the institutional review board of the Brigham and Women's Hospital and the privacy board of Horizon (Blue Cross Blue Shield, hereafter *Horizon*). A waiver of informed consent was granted by the institutional review board and privacy board because of the minimal-risk nature of the study. This study follows the reporting requirements of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Data Source and Patient Population

We used administrative claims data from Horizon, the largest health insurer in New Jersey, with more than 3.8 million beneficiaries. These Health Insurance Portability and Accountability Act–limited data include patient-level claims for medical inpatient and outpatient hospitalizations, procedures, office visits, emergency department visits, and outpatient pharmacy prescription drug claims. These data are also linked with patient enrollment data that include demographic information, such as age and sex, using a scrambled patient identifier, as well as detailed laboratory information, such as hemoglobin (HbA_{1c}) test results, which are regularly collected by Horizon for quality improvement purposes. These data did not contain race/ethnicity or patient zip code data.

Our study population consisted of 6000 patients enrolled in the Targeted Adherence Intervention to Reach Glycemic Control With Insulin Therapy for Patients With Diabetes (TARGIT-Diabetes) pragmatic trial,[12,13] which began enrollment in July 2016 and completed follow-up in October 2017. The parent TARGIT-Diabetes trial is registered with ClinicalTrials.gov. As previously described,[12] this trial evaluated the effect of 3 pharmacist-delivered interventions on insulin persistence and HbA_{1c} levels in patients with diabetes. Patients were included in the trial if they had type 2 diabetes (based on a diagnosis code for type 2 diabetes in administrative claims data or having filled a prescription for an oral hypoglycemic agent), had filled a prescription for basal insulin, were 18 years or older, and had their medical and prescription benefits administered by Horizon.[12,13] By

leveraging linked administrative claims data with clinical laboratory data within a population of patients with type 2 diabetes using insulin, these trial data provide the opportunity to examine the associations of patient factors with glycemic control.

We used baseline (prerandomization) data from TARGIT-Diabetes to conduct this retrospective cohort study. We restricted the trial population to individuals with at least 1 HbA_{1c} value before randomization who were continuously enrolled in insurance benefits for at least 365 days prior to their latest HbA_{1c} test (hereafter, *HbA_{1c} test date*) and who filled a basal insulin prescription in the 180- to 365-day period before the HbA_{1c} test date, specifically detemir, glargine, lispro protamine, or NPH formulations. We used data from July 1, 2014, to October 5, 2016 (the end date of randomization for the parent trial), for this study.

Measurement of Factors

We used the peer-reviewed literature to identify numerous patient factors that have been hypothesized to be associated with diabetes control and that could be measured in routinely collected administrative claims data available to a health care organization, such as a payer.[1,8,10,14] We classified each of these as either being a nonmodifiable patient factor or a potentially modifiable factor, including diabetes care delivery–related factors (**Box**). These factors were evaluated in the 365 days prior to the HbA_{1c} test date. All of these variables and their definitions are provided in eTable 1 in the Supplement.

Nonmodifiable patient factors included demographic characteristics, clinical comorbidities, and indicators associated with disease progression. The demographic data included age and sex and were measured in enrollment files. Clinical comorbidities and indicators associated with disease progression were measured using *International Classification of Diseases, Ninth Revision*[15] or *Tenth Revision*[16] codes in inpatient and outpatient medical claims data and included congestive heart failure, depression, hyperlipidemia, hypertension, kidney disease, liver disease, Alzheimer disease or dementia, diabetic ketoacidosis, hypoglycemia, macrovascular disease (including coronary artery disease and stroke), and microvascular disease (including diabetic nephropathy, neuropathy, and retinopathy).

Conversely, the potentially modifiable factors of diabetes care delivery and patient behavior we measured focused on aspects related to how patients' health care was being delivered. These factors included the type of basal insulin used, whether rapid-acting insulin was filled, and use of adjunctive oral glucose-lowering medications. We assessed potentially modifiable patient behaviors by measuring patients' persistence to basal insulin and extent of using glucose self-testing supplies (measured as number of glucose self-testing supplies claims filled), as regular medication-taking and monitoring are associated with how care is delivered.[9,17,18] We calculated persistence by linking all observed fills in pharmacy claims from the first insulin fill date until the HbA_{1c} test date and evaluating

Box. Nonmodifiable and Potentially Modifiable Diabetes Care Delivery Factors Examined

Nonmodifiable Patient Factors	Potentially Modifiable Factors
Demographic characteristics:	Drug therapy:
Age and sex	Use of rapid-acting insulin, type and use of oral medications, and type of basal insulin used
Clinical comorbidities:	Patient behavior:
Chronic obstructive pulmonary disease, congestive heart failure, depression, hyperlipidemia, hypertension, liver disease, osteoporosis, and Alzheimer disease or dementia	Insulin persistence and extent of using testing supplies
Indicators associated with disease progression or control:	Model of care and insurance structure:
Hypoglycemia, diabetic ketoacidosis, kidney disease, macrovascular disease, and microvascular disease	Having visited an endocrinologist, primary care office visits, use of insulin listed on drug formulary, insulin copayment, and use of mail-order pharmacy service

when an excessive gap in days supplied had occurred (ie, ≥60 days).[19,20] Other diabetes care delivery factors included whether the patient had a visit with an endocrinologist, the number of primary care office visits, patient out-of-pocket copayments for basal insulin, whether the basal insulin was included in Horizon's drug formulary, and use of mail-order pharmacy services to fill insulin prescriptions.

Glycemic Control

Our outcome of interest was adequate glycemic control, defined as an HbA_{1c} level less than 8% (to convert to proportion of total hemoglobin, multiply by 0.01). This cutoff reflects the level that nearly all patients should minimally achieve based on guidelines from the American Diabetes Association,[1] the American Association of Clinical Endocrinologists,[21] and the American College of Physicians[22] and is the quality measure threshold that many major health insurers, including Healthcare Effectiveness Data and Information Set (HEDIS) measures, use as a minimum threshold for patients with diabetes. If patients had multiple HbA_{1c} values in the prerandomization period, we selected the latest HbA_{1c} laboratory value prior to randomization for the glycemic control outcome.

Statistical Analysis

First, we examined the baseline characteristics of the patients in the cohort stratified by those with HbA_{1c} levels less than 8% compared with those with HbA_{1c} levels 8% or higher. We then used bivariate and multivariable modified Poisson regression to examine the independent associations between each of the patient characteristics and adequate glycemic control.[23] Modified Poisson models generate the estimated relative risks (RRs) with robust SEs and are considered appropriate when outcomes are common (ie, incidence ≥5%).[23] These models were adjusted for all of the measured baseline characteristics. We also explored the pairwise correlation coefficients among all regressors included in the models.

As secondary analyses, we used multivariable logistic regression modeling using subsets of factors to generate pseudo R^2 and C statistics.[24] We used these pseudo R^2 and C statistics to explore the extent of variation explained by nonmodifiable patient factors compared with the measured variation explained by potentially modifiable diabetes care delivery and patient behavior factors.

Finally, we conducted several subgroup analyses among patients by sex and age, stratified by the mean age of the sample. Specifically, we repeated the multivariable logistic regression modeling measuring the independent associations between each of the patient characteristics and adequate glycemic control in stratified models by sex subgroup. These findings could theoretically help further improve targeting of interventions aimed at addressing factors associated with diabetes care.

In sensitivity analyses, we used multivariable modified Poisson regression analysis with backward selection for variable selection. Using this method, we reevaluated the independent associations of variables included in the reduced model with adequate glycemic control as the outcome to evaluate the robustness of the original findings from the full model.

Statistical significance was determined using 2-sided tests with an α of 0.05. All analyses were conducted using SAS statistical software version 9.4 (SAS Institute). The study database became available on February 4, 2017, and analyses were conducted until November 13, 2018.

Results

Of 6000 patients in the parent TARGIT-Diabetes trial, 1423 patients met the inclusion criteria for this cohort study using their baseline data (eFigure in the Supplement); of these patients, 565 (39.7%) were women, and the mean (SD) age was 56.4 (9.0) years. In total, 690 patients (48.5%) had adequate glycemic control, defined as an HbA_{1c} level less than 8%. The overall mean (SD) HbA_{1c} level was 8.4% (1.7%).

The baseline characteristics of the study cohort, stratified by glycemic control, are described in **Table 1**. While the prevalence of clinical comorbidities was fairly similar between the patients with

adequate glycemic control and those with inadequate glycemic control, more differences between groups were noted for the diabetes care delivery factors. For example, compared with patients with inadequate glycemic control, patients with adequate glycemic control had higher rates of insulin persistence (570 patients [77.7%] vs 567 patients [82.2%]) and having visited an endocrinologist (292 patients [39.8%] vs 365 patients [52.9%]).

The results of the multivariable regression analyses are shown in **Table 2**. Only 1 nonmodifiable factor, age, was associated with adequate glycemic control (adjusted RR per 1-unit increase, 1.01; 95% CI, 1.00-1.02; *P* = .03). Of the potentially modifiable diabetes care delivery and patient behavioral factors, persistent use of basal insulin (adjusted RR, 1.20; 95% CI, 1.00-1.43; *P* = .048), greater filling of glucose self-testing supplies (adjusted RR per 1-unit increase, 1.01; 95% CI, 1.01-1.02; *P* = .002), visiting an endocrinologist (adjusted RR, 1.41; 95% CI, 1.19-1.67; *P* < .001), and receipt of insulin prescriptions by mail order (adjusted RR, 1.23; 95% CI, 1.03-1.48; *P* = .04) were independently

Table 1. Baseline Characteristics of the Study Participants

Factor	No. (%)	
	Adequate Glycemic Control (n = 690)[a]	Inadequate Glycemic Control (n = 733)
Nonmodifiable		
Women	261 (37.8)	304 (41.5)
Age, mean (SD), y	57.2 (8.6)	55.6 (9.3)
Clinical comorbidities		
Congestive heart failure	36 (5.2)	41 (5.6)
Chronic obstructive pulmonary disease or asthma	96 (13.9)	88 (12.1)
Depression	57 (8.3)	63 (8.6)
Hyperlipidemia	517 (74.9)	537 (73.3)
Hypertension	547 (79.3)	564 (76.9)
Liver disease	45 (6.5)	47 (6.4)
Osteoporosis	41 (5.9)	37 (5.1)
Alzheimer disease or dementia	12 (1.7)	3 (0.4)
Indicators associated with disease progression or control		
Hypoglycemia	23 (3.3)	28 (3.8)
Diabetic ketoacidosis	12 (1.7)	18 (2.5)
Kidney disease	429 (62.2)	438 (59.8)
Macrovascular disease[b]	145 (21.0)	154 (21.0)
Microvascular disease[c]	231 (33.5)	237 (32.3)
Potentially Modifiable		
Drug therapy		
Adjunct rapid-acting insulin use	378 (55.8)	405 (55.3)
Unique oral diabetes drugs used, mean (SD), No.	2.1 (1.2)	2.2 (1.2)
Type of basal insulin used		
Glargine, 100 µIU/mL	385 (55.8)	410 (55.9)
Detemir	209 (30.2)	220 (30.0)
NPH	35 (5.1)	30 (4.1)
Lispro protamine	48 (7.0)	64 (8.7)
Glargine, 300 µIU/mL	13 (1.9)	10 (1.3)
Patient behavior		
Insulin persistence	567 (82.2)	570 (77.7)
Glucose self-testing supply fills, mean (SD), No.	1.32 (3.7)	0.66 (2.4)
Model of care and insurance structure		
Visited an endocrinologist	365 (52.9)	292 (39.8)
Primary care office visits, mean (SD), No.	6.8 (10.9)	6.1 (6.9)
Use of insulin listed in drug formulary	612 (88.7)	652 (90.0)
Insulin copayment, mean (SD), $	37.0 (46.6)	34.7 (43.8)
Use of mail-order pharmacy service	156 (22.6)	119 (16.2)

SI conversion factor: To convert insulin to picomoles per liter, multiply by 6.945.

[a] Adequate control was defined by a hemoglobin A_{1c} level less than 8% (to convert to proportion of total hemoglobin, multiply by 0.01).

[b] Includes coronary artery disease and stroke.

[c] Includes diabetic nephropathy, neuropathy, and retinopathy.

associated with adequate glycemic control. Pairwise correlations between the nonmodifiable and potentially modifiable factors are shown in eTable 2 in the Supplement.

The secondary analyses of the pseudo R^2 and C statistics are shown in **Table 3**. By these metrics, discriminative ability was modest overall (C statistic including all measured factors, 0.689). However, models using the measured diabetes care delivery and patient behavior factors explained more variation than all of the measured nonmodifiable factors, such as patient demographic, clinical, or diabetes disease progression factors, combined (all nonmodifiable factors: pseudo R^2 = 0.04; all potentially modifiable factors: pseudo R^2 = 0.11).

The sensitivity analyses in the reduced model using backward selection resulted in similar findings to those in the full model (eTable 3 in the Supplement). For example, number of glucose self-testing supply fills (adjusted RR per 1-unit increase, 1.01; 95% CI, 1.00-1.02; P = .002), visiting an endocrinologist (adjusted RR, 1.35; 95% CI, 1.16-1.58; P < .001), and mail-order pharmacy services use (adjusted RR, 1.25; 95% CI, 1.04-1.49; P = .02) had similar associations with adequate glycemic

Table 2. Association of Factors With Adequate Glycemic Control[a]

Factor	Relative Risk (95% CI)[b]	
	Unadjusted	Adjusted
Nonmodifiable		
Women	0.92 (0.79-1.08)	0.92 (0.78-1.08)
Age[b]	1.01 (1.00-1.02)	1.01 (1.00-1.02)
Clinical comorbidities		
Congestive heart failure	0.96 (0.69-1.35)	0.95 (0.66-1.37)
Chronic obstructive pulmonary disease or asthma	1.09 (0.88-1.35)	1.09 (0.88-1.37)
Depression	0.98 (0.75-1.28)	0.94 (0.71-1.24)
Hyperlipidemia	1.05 (0.88-1.24)	0.98 (0.81-1.18)
Hypertension	1.07 (0.89-1.29)	1.04 (0.84-1.28)
Liver disease	1.01 (0.75-1.37)	1.04 (0.75-1.40)
Osteoporosis	1.09 (0.79-1.49)	1.05 (0.76-1.46)
Alzheimer disease or dementia	1.66 (0.94-2.94)	1.44 (0.79-2.63)
Indicator associated with disease progression or control		
Hypoglycemia	0.93 (0.61-1.41)	0.92 (0.60-1.40)
Diabetic ketoacidosis	0.82 (0.46-1.45)	0.90 (0.50-1.61)
Kidney disease	1.05 (0.90-1.23)	0.94 (0.80-1.12)
Macrovascular disease	1.00 (0.83-1.20)	0.93 (0.76-1.13)
Microvascular disease	1.03 (0.88-1.20)	0.95 (0.81-1.13)
Potentially Modifiable		
Drug therapy		
Adjunct rapid-acting insulin use	0.99 (0.85-1.15)	0.87 (0.73-1.03)
No. of unique oral diabetes drugs[c]	0.99 (0.93-1.05)	0.97 (0.90-1.03)
Insulin type[d]		
Detemir	1.01 (0.86-1.18)	1.01 (0.85-1.20)
NPH	1.12 (0.79-1.57)	0.97 (0.64-1.45)
Lispro protamine	0.88 (0.65-1.17)	0.70 (0.42-1.18)
Glargine, 300 µIU/mL	1.22 (0.71-2.12)	1.16 (0.66-2.06)
Patient behavior		
Insulin persistence	1.16 (0.95-1.41)	1.20 (1.00-1.43)
No. of glucose self-testing fills[c]	1.01 (1.00-1.02)	1.01 (1.01-1.02)
Model of care and insurance structure		
Visited an endocrinologist	1.31 (1.13-1.52)	1.41 (1.19-1.67)
No. of primary care office visits[c]	1.00 (0.99-1.01)	1.00 (0.99-1.01)
Use of insulin in drug formulary	0.99 (0.78-1.25)	0.78 (0.51-1.20)
Insulin copayment[c]	1.00 (0.99-1.00)	1.00 (0.99-1.00)
Use of mail-order pharmacy service	1.22 (1.02-1.46)	1.23 (1.03-1.48)

SI conversion factor: To convert insulin to picomoles per liter, multiply by 6.945.

[a] Adequate control was defined by a hemoglobin A_{1c} level less than 8% (to convert to proportion of total hemoglobin, multiply by 0.01).

[b] Calculated using not having the factor as the reference.

[c] Calculated per 1-unit increase.

[d] Calculated using use of glargine, 100 µIU/mL, as the reference.

control as in the full model, although insulin persistence was no longer statistically significantly associated with adequate glycemic control (adjusted RR, 1.17; 95% CI, 0.96-1.42; *P* = .12). Age (adjusted RR per 1-unit increase, 1.01; 95% CI, 1.00-1.02; *P* = .03) was the only nonmodifiable patient factor that remained statistically significant in the reduced model. The results of the multivariable regression analyses by sex and age subgroups are shown in eTable 4 in the Supplement. While the CIs were fairly wide among the diabetes care delivery and patient behavior factors, the association of visiting an endocrinologist with adequate glycemic control appeared to be stronger among men (adjusted RR, 1.45; 95% CI, 1.16-1.80; *P* = .001) than women (adjusted RR, 1.26; 95% CI, 0.96-1.66; *P* = .09), while mail-order pharmacy services use was associated with adequate glycemic control among women (adjusted RR, 1.39; 95% CI, 1.02-1.90; *P* = .04) but not men (adjusted RR, 1.15; 95% CI, 0.91-1.45; *P* = .25). Few differences were noted by age subgroup.

Discussion

In this cohort study of patients with type 2 diabetes using basal insulin, we evaluated the independent associations of nonmodifiable patient factors and potentially modifiable diabetes care delivery and patient behavioral factors with glycemic control. We found that the most notable factors appeared to be the nature of patients' interactions with the health care system and behaviors in the health care system. Specifically, insulin persistence, greater use of glucose self-testing supplies, receipt of prescriptions by mail order, and visiting an endocrinologist were the factors most strongly associated with adequate diabetes control.

The associations that we observed of the diabetes care factors with adequate glycemic control could be explained in several ways. First, several of the factors we explored, such as more frequent use of glucose self-testing supplies or regular use of insulin, may represent greater patient engagement with the health care system. Previous studies have also observed that more consistent medication-taking is associated with fewer diabetes-related adverse outcomes.[25-27] Other factors, such as endocrinologist involvement, use of mail-order pharmacy services, or use of basal insulin listed on the insurance drug formulary, may represent more collaborative or connected health care. Other studies have also suggested that enhanced systems for care management and coordination can help patients to achieve glycemic control.[28-31]

In our study, glycemic control appeared to be most strongly associated with the factors related to how diabetes care was delivered and used, rather than the nonmodifiable clinical characteristics that are often considered in clinical practice. It is not possible from the study design to identify the specific reasons behind these observed associations, and other unmeasurable factors in these data, such as socioeconomic status, could be alternative explanations. Furthermore, while model explanatory power using these factors was modest (ie, pseudo R^2 and C statistics), our findings are

Table 3. Explained Variation in Adequate Glycemic Control[a]

Factor Type	Pseudo R^2	C Statistic
Nonmodifiable		
Demographic	0.03	0.580
Clinical	0.02	0.557
Indicators associated with disease progress or control	0.01	0.537
All nonmodifiable factors	0.04	0.598
Potentially modifiable		
Drug therapy	0.04	0.595
Patient behavior	0.02	0.569
Model of care and insurance structure	0.05	0.610
All potentially modifiable factors	0.11	0.661
All	0.15	0.689

[a] Adequate control was defined by a hemoglobin A_{1c} level less than 8% (to convert to proportion of total hemoglobin, multiply by 0.01).

in line with prior research in this area, and our overall objective was to identify some factors that may be relevant and measurable in routinely collected claims data.[32,33]

Of particular note, we also did not observe an association of adequate glycemic control with type of basal insulin that was used by patients. This finding is consistent with emerging data on the comparative effectiveness and safety of different basal insulins for type 2 diabetes.[34,35] Two studies published in 2018 reported similar associations of different basal formulations with glucose-lowering ability in real-world practice.[34,35]

The existing literature has mainly concentrated on patients with type 2 diabetes who do not use insulin and the extent to which nonmodifiable factors are associated with diabetes control.[7,8,10,36] For example, age and duration of diabetes have been elucidated as factors associated with a patient's glycemic control.[7,8,10,36] In addition, depression has been found to be associated with glycemic control.[37] Moreover, the existing studies of factors associated with glycemic control have also generally examined individual factors rather than comprehensive sets of factors.

Overall, our findings suggest that nonmodifiable factors could be less relevant compared with other factors associated with glycemic control than prior studies in other populations have suggested.[7,9,38] While our study similarly confirms that age is an important factor associated with glycemic control, other clinical and demographic factors that we measured appeared to be less associated with glycemic control than prior research has suggested.

Regardless of explanation, these results suggest that the nature of care that patients receive may be important and potentially modifiable. Moreover, the findings from this study also suggest several patient-centered quality improvement interventions that could be relevant to improving glycemic control, such as optimizing access to glucose self-testing supplies, focusing on insulin adherence and persistence, ensuring access to an endocrinologist, or supporting regular physician's office visits. Any potential differences in exploratory analysis of subgroups by sex could be associated with perceptions of the disease or possible differences in how diabetes is practically managed.[39] Future studies could build on these exploratory findings.

Limitations

These findings should be interpreted in light of several limitations. First, this is an observational study based on administrative claims data, as one of the objectives was to identify factors that may be relevant to health care organizations or payers working with routinely collected population data. Therefore, not all potential factors for glycemic control could be measured in these data, including additional socioeconomic status variables, such as educational attainment or wealth, or psychosocial factors, such as personality traits or socioemotional skills, which could be associated with appropriate diabetes care.[40] The factors we were able to measure could also be proxies for some of these omitted socioeconomic or psychosocial factors and may be largely nonmodifiable.[41,42] For example, the association observed of visiting an endocrinologist with appropriate glycemic control could be itself associated with educational attainment.[29,31] Regardless, the factors we measured here could be measured by health care plans or other clinical organizations for the design and implementation of interventions in other routinely collected data sources.

In addition, any findings of the association of patient factors with glycemic control cannot be interpreted as causal, only as associations. We also did not have detailed clinical information about patients beyond laboratory results, and diabetes control was measured via HbA_{1c} tests that were reported to the payer. Insulin persistence and other factors related to treatment use were also measured indirectly in patients. Additionally, these results cannot be fully generalized to other payer systems or patient populations, such as Medicare or Medicaid.

Conclusions

Based on the findings of this cohort study, we conclude that potentially modifiable diabetes care factors could have a stronger association with achieving adequate glycemic control as measured by

an HbA_{1c} level less than 8% than patient factors, such as clinical comorbidities or sex, that cannot be altered. Specifically, frequency of glucose self-testing, insulin persistence, and visiting an endocrinologist may be important factors in understanding which adult patients with insulin-treated type 2 diabetes may achieve adequate glycemic control. Given their potential for intervention in these modifiable factors, future efforts should focus on these potentially modifiable factors as points for intervention to improve diabetes outcomes.

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Corresponding Author: Julie C. Lauffenburger, PharmD, PhD, Brigham and Women's Hospital, Harvard Medical School, 1620 Tremont St, Ste 3030, Boston, MA 02120 (jlauffenburger@bwh.harvard.edu).

Author Affiliations: Center for Healthcare Delivery Sciences, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts (Lauffenburger, Ghazinouri, Choudhry); Division of Pharmacoepidemiology and Pharmacoeconomics, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts (Lauffenburger, Ghazinouri, Choudhry); Center for Healthcare Delivery Sciences, Division of Pharmacoepidemiology and Pharmacoeconomics, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts (Lee); Harvard T.H. Chan School of Public Health, Harvard University, Boston, Massachusetts (Lee); Division of Cardiovascular Medicine, Hospital of the University of Pennsylvania, Philadelphia (Lewey); Horizon Blue Cross Blue Shield, Newark, New Jersey (Jan); Department of Pharmacy Practice and Administration, Rutgers State University of New Jersey, New Brunswick (Jan).

Author Contributions: Dr Lauffenburger 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.

Concept and design: Lauffenburger, Lewey, Jan, Ghazinouri, Choudhry.

Acquisition, analysis, or interpretation of data: Lauffenburger, Lewey, Jan, Lee, Choudhry.

Drafting of the manuscript: Lauffenburger, Jan.

Critical revision of the manuscript for important intellectual content: Lewey, Jan, Lee, Ghazinouri, Choudhry.

Statistical analysis: Lauffenburger.

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SUPPLEMENT.

eTable 1. Measurement of Factors
eFigure. Cohort Flow Diagram
eTable 2. Pairwise Correlation Coefficients Between Regressors (P-Values)
eTable 3. Sensitivity Analysis of Association of Factors With Adequate Glycemic Control: Reduced Model
eTable 4. Association of Factors With Adequate Glycemic Control by Sex Subgroup