

ORIGINAL RESEARCH

Comorbidities, Utilization, and Quality of Care as Predictors of Diabetes Complications

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Objective: To determine factors associated with diabetes complications, measured by the Diabetes Complications Severity Index (DCSI).

Research Design and Methods: This longitudinal analysis used insurer data (2016 – 2020) and included Medicare Advantage beneficiaries aged 65 and older with type 2 diabetes. The dependent variable was DCSI. Independent variables included year, demographics (age, sex, race/ethnicity, language, dual eligibility, rurality), comorbidities (Charlson (CCI) and Functional Comorbidity Indexes (FCI)), utilization (risk adjustment scores, emergency department, urgent care, outpatient, physician, inpatient, and pharmacy claims), and quality measures (hemoglobin A1c and blood pressure control). Four multilevel mixed-effects models were developed: demographics (model 1), comorbidities (model 2), utilization (model 3), and quality measures (model 4).

Results: We included 49,843 individuals. Model 1 showed a relationship between year (IRR=1.32, $p<0.001$, 2020 vs. 2016), sex (IRR=0.86, $p<0.001$, female vs. male), race/ethnicity (IRR=1.06, $p<0.001$, Black vs. white), dual eligibility (IRR=1.26, $p<0.001$ yes vs. no), and rurality (IRR=0.90, $p<0.001$, yes vs. no). CCI (IRR=1.18, $p<0.001$) and FCI (IRR=1.08, $p<0.001$), which share overlapping and distinct comorbidities with DCSI, were associated with higher DCSI. Emergency department visits (IRR=1.01, $p<0.05$) and physician visits (IRR=1.003, $p<0.05$) were associated with higher DCSI. Not meeting the blood pressure quality measure was linked to higher DCSI (IRR=1.10, $p<0.05$), while hemoglobin A1c control was not.

Conclusions: Year, male sex, race/ethnicity, non-rural status, comorbidities, emergency department visits, and not meeting the blood pressure measure were linked to higher DCSI. Future research should develop strategies for high-risk groups in primary care settings.

Keywords: Diabetes, Diabetes Complications, Health Insurance, Medicare Advantage, Primary Health Care, Services Utilization, Quality of Care

In the United States (US), chronic diseases are projected to double between 2020 and 2050.¹ Diabetes mellitus is a particularly deadly chronic disease, that can diminish quality of life, increase financial burdens, and shorten lifespans.²⁻⁴ In 2021, 38.4 million individuals, or 11.6% of Americans, were living with either diagnosed or undiagnosed diabetes.⁵ This figure is projected to rise to 54.9 million by 2030.⁶ Individuals with diabetes mellitus have a higher risk for acute and long-term complications, such as hyperglycemia, nervous system damage, kidney disease, eye damage, and cardiovascular events.⁷ The high cost of treating diabetes complications increases the urgency of predicting and preventing these adverse outcomes.^{8,9} Diabetes is addressed in one out of every seven office visits in the

US, and 84% of individuals with diabetes see a primary care physician annually.^{10,11} Together, these figures highlight the central role of primary care in managing diabetes and reducing the burden of its complications.

Preventing diabetes complications remains a key, national priority that is codified within the objectives of Healthy People 2030.¹² These efforts aim to curb the high costs associated with diabetes mellitus, which now accounts for one out of every four dollars spent on health care in the US.⁹ Individuals with complications disproportionately contribute to these costs, with complications accounting for over half of an individual's diabetes-related expenses.¹³ Among patients with diabetes mellitus, one-third are expected to have two or more complications over

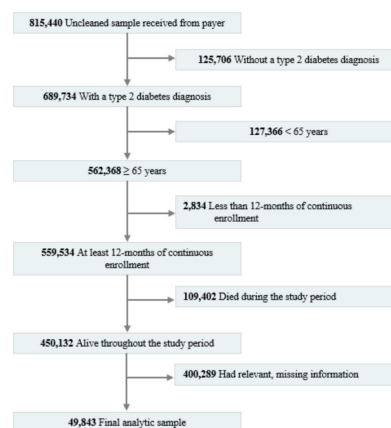
their lifetimes.¹⁴ Thus, identifying those at high risk for complications and connecting them with evidence-based interventions is critical for meeting national goals.

One way to quantify diabetes-related complications is to use the Diabetes Complications Severity Index (DCSI), a 14-point scale that combines the number and severity of complications.¹⁴ Prior studies have found that the DCSI predicts poor outcomes that are important to patients.¹⁴ Specifically, each one-point increase in the DCSI is associated with a \$2744 increase in health care costs,¹⁵ a 34% increase in mortality, and a 29% increase in hospitalizations.¹⁴ This index is important because it provides a standardized method for evaluating the severity of diabetes-related complications and facilitates more precise risk stratification. By quantifying and eventually predicting diabetes-associated complications, clinicians can ensure that scarce resources are given to those who will benefit the most.

Less is known about the factors associated with increases in DCSI and the interventions that can halt upward trends. One study of veterans found that having mental health or substance use diagnoses was associated with lower DCSI scores.¹⁶ Another concluded that pancreatic cancer, Hispanic ethnicity, and Black race were associated with higher DCSIs.¹⁷ Similarly, age, sex, and poverty have been linked to higher DCSIs.^{18,19} Unfortunately, these studies have limited generalizability because they were cross-sectional,¹⁹ involved targeted populations (like veterans),¹⁶ or were conducted outside the US.^{20,21} A limited number of studies explored the relationship between utilization and DCSI and found that enhanced access to outpatient services can mitigate expected increases.^{20,21} In addition to improved access, a wide range of interventions have the potential to prevent the accumulation of complications, though few studies have examined changes in DCSI. For example, providing patients with tools for self-management, including patient education, can improve glycemic control.²² Newer interventions, such as glucagon-like peptide-1 receptor agonists,²³ expanded team members,²⁴ and digital applications,²⁵ have similarly improved health. Unfortunately, these can be out of reach for many, due to costs, availability, and shortages.

To identify those at highest risk, we examine a longitudinal, national cohort of older adults in the US and combine the covariates used in the aforementioned studies into a unified analysis. We also explore the influence of widespread quality measures (for diabetes mellitus, blood pressure, and cholesterol control) on the trajectory of DCSI.²⁶ While improvements in chronic disease control should theoretically reduce the risk of complications, it's unknown whether meeting these measures is ultimately associated with lower DCSI scores. To this end, this paper aims to identify the demographic, comorbidity, utilization, and quality of care factors associated with DCSI scores to guide interventions that reduce diabetes morbidity and mortality.

Figure 1. Flow Diagram for the Analytic Sample.



Research Design and Methods

Data

This longitudinal analysis assesses the factors associated with DCSI during the study period (2016–2020). Data were obtained from a national health payer, including enrollees with at least 12 months of continuous enrollment. The data included enrollment files, visit-level medical claims, and outpatient pharmacy claims data from Humana Inc. This US-based company provides Medicare Advantage, stand-alone Medicare prescription drug plans, and commercial plan offerings. The data encompassed demographic information, comorbidities, utilization, and member quality measures.

The population studied included individuals (1) aged 65 years and older; (2) who have a primary diagnosis of type 2 diabetes; (3) are enrolled in Medicare Advantage, including those with disabled status, special needs plans, and dual eligibility (which includes those who are eligible for both Medicaid and Medicare); (4) are continuously enrolled for the entire study period; and (5) fully complete information (no missing values). Individuals were excluded if they died during the study period or enrolled in group plans that are contractually excluded. Of the initial 323,306 Medicare Advantage visit-level records, we included 196,126 records representing 49,843 unique individuals who met the eligibility criteria (Figure 1).

Measurement

The dependent variable was DCSI, measured in 2020.²⁷ First introduced by Young et al, the DCSI score is a tool used to assess the severity of diabetes complications.¹⁴ It is based on the presence and severity of seven groups of diabetic complications, including retinopathy (e.g., retinal detachment and blindness), nephropathy (e.g., nephrotic syndrome and renal failure), neuropathy (e.g., nerve palsy and autonomic neuropathy), cerebrovascular disease (e.g., stroke), cardiovascular disease (e.g., myocardial infarction and heart failure), peripheral vascular disease (e.g., thromboembolism and gangrene), and metabolic complications

(e.g., ketoacidosis and hyperosmolar hyperglycemic nonketotic syndrome). In computing the score, complications are categorized into two or three levels: 0 for no abnormality, 1 for some abnormality, and 2 for severe abnormality (range 0-13; 14 total levels). The max score is 13 because neuropathy has two rather than three levels (not present = 0, abnormal = 1). The final score represents the sum of the scores across all seven groups of complications, with 2 to 12 individual complications per group. Higher scores indicate more severe or numerous complications.

The primary independent variable was time, captured by year (2016-2020, with each year as a fixed effect). We adjusted for the following sociodemographic characteristics: [(age (65-69 vs. 70-74 vs. 75-79 vs. 80-84 vs. 85-89 vs. 90+), sex (male vs. female), race/ethnicity (Non-Hispanic White vs. Non-Hispanic Black vs. Other vs. Asian vs. Hispanic vs. Native American), primary language (English vs. Spanish vs. Other), dual eligibility status (no vs. yes), and patient geographic residence (rural vs. non-rural)]; comorbidities/risk indices [(Charlson Comorbidity Index (CCI), Functional Comorbidity Index (FCI), Medicare advantage risk scores (Centers for Medicare and Medicaid Services risk adjustment score based on hierarchical condition categories) and prescription risk scores²⁸]; utilization patterns [(for emergency department, all physician visits (including both primary and specialty care visits), and inpatient admits)], and quality, [(captured by the Healthcare Effectiveness Data and Information Set (HEDIS) measures for hemoglobin A1c (HbA1c) and blood pressure control)].^{29,30} We used International Classification of Diseases codes (ICD-10) for diagnoses, Current Procedural Terminology (CPT) codes for utilization, and Logical Observation Identifiers and Names and Codes (LOINC) for quality measures. The CCI is a composite measure that predicts mortality while FCI predicts functional limitations. Both indices include congestive heart failure, myocardial infarction, stroke, peripheral vascular disease, and chronic obstructive pulmonary disease. FCI includes conditions that affect physical functioning, like arthritis, visual impairment, and hearing impairment. In contrast, CCI includes conditions that affect mortality including metastatic cancer and Acquired Immunodeficiency Syndrome.

Analysis

We used multivariate analysis of variance to assess differences in baseline characteristics. To examine factors associated with accumulating diabetes complications over time in this cohort, we used four multilevel mixed effects models with member ID as a random effect to account for repeated DCSI scores nested within individuals. The models used the following set of variables: year+ demographics only (model 1), year+ demographics + comorbidities (model 2), year+ demographics + prior utilization patterns (model 3), and year+ demographics + prior utilization patterns + quality measures (model 4). These models used a progressively expanding set of variables with one exception. We initially included CCI and FCI as independent variables in all 4 models, tested the variance inflation factor, and found no risk of multicollinearity for FCI and CCI. However, using the

Hausman test on the FCI and CCI values, we found that both were endogenous to DCSI in the utilization (model 3) and quality (model 4). Accordingly, we excluded CCI and FCI from models 3 and 4. Considering that DCSI is a count variable, with values from 0-13 only, poisson specification was used for the multilevel mixed effects models. An independent institutional review board approved this study. Patients and members of the public were not involved in the design and execution of this study. All data management and analyses were performed using SAS 9.4.³¹ Findings were considered statistically significant at $P < .05$.

Data and Resource Availability

The datasets generated during and/or analyzed during the current study are not publicly available because they are proprietary and contain protected health information. These data sets could be made available from the data steward, although transfer of the data would need to be negotiated with the entity from which the data originated.

Results

The analysis included data from 2016 to 2020 for 49,843 individuals. In 2016, over half of the sample was female (Table 1), and nineteen percent of the sample identified as Black, while 2.5% identified as Hispanic. Over sixty percent reported English as their primary language. The mean DCSI in 2016 was 2.17.

In model 1 (demographics), each subsequent year was correlated with higher DCSI scores relative to the reference year 2016 (Table 2). Females (IRR: 0.86) had significantly lower rates of increasing DCSI scores, compared to their male counterparts. We observed a dose response relationship between age and DCSI score, with progressively higher scores observed in older age groups compared to the reference group (65-69 years), ranging from an IRR of 1.08 (70-74 years) to 1.49 (90+ years, $p < 0.01$). Compared to Non-Hispanic white older adults, Black older adults (IRR: 1.06, $p < 0.01$) had significantly higher rates of increasing DCSI scores, while Hispanic (IRR: 0.94; $p < 0.01$), Asian (IRR: 0.78; $p < 0.01$) and other race older adults (IRR: 0.86; $p < 0.01$) had lower rates of increase. Compared to English speakers, those who spoke Spanish as their primary language (IRR: 1.02, $p = 0.02$) had significantly higher rates of increasing DCSI. Older adults eligible for dual enrollment (IRR: 1.26, $p < 0.01$) had a 26% higher rate of increasing DCSI scores, compared to those not eligible, while residence in a rural area (IRR: 0.90, $p = 0.02$) was associated with lower rates of increasing DCSI scores compared to non-rural residents.

In model 2 (Table 2), CCI (IRR: 1.18; $p < 0.01$) and FCI (IRR: 1.08; $p < 0.01$) were the strongest predictors of increasing DCSI scores. Consistent with model 1, year, Black race and dual eligibility remained significantly associated with higher rates of DCSI increase, while female sex, Asian and other races, and rural residence were associated with lower rates of increasing DCSI scores. While age remained significant in model 2, older age groups demonstrated an inverse relationship with DCSI.

Table 1. Baseline Characteristics, 2016-2020.

Parameter	2016	2017	2018	2019	2020	p-value
Demographics, n (%)						
Sex						0.94
Male	20,876 (47.2)	20,558 (47.3)	18,866 (47.3)	17,103 (47.2)	15,186 (47.0)	
Female	23,333 (52.8)	22,945 (52.7)	20,997 (52.7)	19,146 (52.8)	17,116 (53.0)	
Age group						<0.001
65-69	11,477 (26.0)	8,831 (20.3)	6,257 (15.7)	4,133 (11.4)	2,688 (8.3)	
70-74	13,170 (29.8)	13,217 (30.4)	12,258 (30.8)	11,328 (31.3)	9,957 (30.8)	
75-79	9,880 (22.4)	10,611 (24.4)	10,447 (26.2)	9,994 (27.6)	9,154 (28.3)	
80-84	5,723 (13.0)	6,253 (14.4)	6,278 (15.8)	6,164 (17.0)	6,034 (18.7)	
85-89	2,818 (6.4)	3,148 (7.2)	3,150 (7.9)	3,141 (8.7)	3,021 (9.4)	
90+	1,141 (2.6)	1,443 (3.3)	1,473 (3.7)	1,489 (4.1)	1,448 (4.5)	
Race/Ethnicity						0.18
White	32,785 (74.2)	32,389 (74.5)	29,574 (74.2)	26,849 (74.1)	23,652 (73.2)	
Black	8,408 (19.0)	8,222 (18.9)	7,661 (19.2)	7,022 (19.4)	6,471 (20.0)	
Other	922 (2.1)	921 (2.1)	842 (2.1)	758 (2.1)	699 (2.2)	
Asian	870 (2.0)	830 (1.9)	771 (1.9)	693 (1.9)	639 (2.0)	
Hispanic	1,099 (2.5)	1,023 (2.4)	906 (2.3)	836 (2.3)	756 (2.3)	
Native American	125 (0.3)	118 (0.3)	109 (0.3)	91 (0.3)	85 (0.3)	
Primary language						<0.001
English	28,185 (63.8)	27,941 (64.2)	26,665 (66.9)	25,178 (69.5)	22,322 (69.1)	
Spanish	2,063 (4.7)	1,933 (4.4)	1,701 (4.3)	1,570 (4.3)	1,363 (4.2)	
Other	13,961 (31.6)	13,629 (31.3)	11,497 (28.8)	9,501 (26.2)	8,617 (26.7)	
Dually eligible						<0.001
No	37,952 (85.9)	37,529 (86.3)	34,687 (87.0)	31,563 (87.1)	28,113 (87.0)	
Yes	6,257 (14.2)	5,974 (13.7)	5,176 (13.0)	4,686 (12.9)	4,189 (13.0)	
Rural						0.27
No	34,962 (79.1)	34,311 (78.9)	31,511 (79.1)	28,730 (79.3)	25,684 (79.5)	
Yes	9,247 (20.9)	9,192 (21.1)	8,352 (21.0)	7,519 (20.7)	6,618 (20.5)	
Continuous variables, mean (SE)						
Diabetes Complications Severity Index	2.17 (0.01)	2.47 (0.01)	2.63 (0.01)	2.78 (0.01)	2.81 (0.01)	<0.001

Parameter	2016	2017	2018	2019	2020	p-value
Charlson Comorbidity Index	6.16 (0.01)	6.38 (0.01)	6.58 (0.01)	6.82 (0.01)	6.89 (0.01)	<0.001
Functional Comorbidity Index	3.84 (0.01)	3.88 (0.01)	3.92 (0.01)	4.09 (0.01)	3.96 (0.01)	<0.001
Last risk score: Medicare Advantage	1.31 (0.00)	1.38 (0.00)	1.41 (0.00)	1.46 (0.01)	1.48 (0.01)	<0.001
Last risk score: Prescription	1.19 (0.00)	1.24 (0.00)	1.22 (0.00)	1.23 (0.00)	1.20 (0.00)	<0.001
Total count: Annual emergency department claims	0.54 (0.01)	0.54 (0.01)	0.51 (0.01)	0.50 (0.01)	0.42 (0.01)	<0.001
Total count: Annual urgent care claims	0.08 (0.00)	0.09 (0.00)	0.10 (0.00)	0.11 (0.00)	0.12 (0.00)	<0.001
Total count: Annual outpatient claims	8.23 (0.05)	8.94 (0.06)	9.29 (0.07)	9.87 (0.08)	9.88 (0.11)	<0.001
Total count: Annual physician visit claims	6.03 (0.06)	7.00 (0.07)	7.60 (0.09)	7.91 (0.09)	7.30 (0.09)	<0.001
Total count: Annual inpatient admit claims	0.25 (0.00)	0.29 (0.00)	0.30 (0.00)	0.29 (0.00)	0.28 (0.00)	<0.001
Total count: Annual pharmacy claims	44.59 (0.15)	43.61 (0.15)	43.48 (0.17)	44.35 (0.17)	46.60 (0.18)	<0.001
Blood pressure < 140/90 quality measure not achieved	0.21 (0.00)	0.24 (0.00)	0.20 (0.00)	0.21 (0.00)	0.20 (0.00)	<0.001
Hemoglobin A1c < 9% quality measure not achieved	0 (omitted)	0.37 (0.00)	0.30 (0.00)	0.28 (0.00)	0.25 (0.00)	<0.001

SE = standard error

In model 3 (Table 2), after accounting for demographics, risk scores, and healthcare utilization variables, several factors were significantly associated with increasing DCSI scores. Each subsequent year remained significantly associated with higher rates of increasing DCSI scores, with IRRs ranging from 1.10 (2017) to 1.19 (2020). Females had lower rates of increasing DCSI scores compared to males (IRR = 0.87, $p < 0.01$). In contrast, progressively higher DCSI scores were observed with increasing age, with the oldest groups (90+) demonstrating the highest rate relative to the 65–69 reference group (IRR = 1.46, $p < 0.01$). Black race remained associated with higher rates of increase (IRR = 1.08), $p < 0.01$, while Asian and other race groups had lower rates (IRR = 0.95 and 0.96, respectively, $p < 0.01$). Spanish as a primary language (IRR: 1.04, $p = 0.02$) was associated with significantly higher rates DCSI increases. Dual eligibility was modestly associated with higher rates (IRR = 1.03, $p < 0.02$), whereas rural residence was associated with lower rates (IRR = 0.95, $p < 0.01$). Among clinical predictors, the Medicare Advantage risk score (IRR = 1.10, $p < 0.01$), prescription risk score (IRR = 1.09, $p < 0.01$), and several measures of healthcare utilization—including annual ED visits (IRR = 1.01, $p < 0.01$), urgent care visits (IRR = 1.01, $p < 0.01$), and inpatient admits (IRR = 1.07, $p < 0.01$)—were significantly associated with DCSI progression.

In model 4 (Table 2), which additionally included quality measures for blood pressure and hemoglobin A1c, the overall pattern remained similar to model 3. Each year remained positively associated with DCSI progression (IRR: 1.10–1.19, all $p < 0.01$). Female sex (IRR = 0.84, $p < 0.01$),

Asian (IRR = 0.89, $p = 0.02$) and other race (IRR = 0.93, $p < 0.01$), and rural residence (IRR = 0.92, $p < 0.01$) were associated with lower rates of DCSI increase, while Black race (IRR = 1.08, $p < 0.01$), Spanish as primary language (IRR: 1.04, $p < 0.01$) and dual eligibility (IRR = 1.06, $p < 0.01$) were associated with higher rates. A clear dose-response relationship was observed with age: compared to adults aged 65–69, those aged 70–74 had an IRR of 1.09, 75–79 had 1.25, 80–84 had 1.38, 85–89 had 1.50, and 90+ had 1.51 ($p < 0.01$ for all). Black race (IRR: 1.08, $p < 0.01$) and dual eligibility (IRR: 1.06–1.26, $p < 0.01$) were associated with greater increases. Clinical and utilization factors largely retained significance, with Medicare Advantage risk score (IRR = 1.11), prescription risk score (IRR = 1.09), annual inpatient admissions (IRR = 1.07), and annual ED and urgent care claims (IRR = 1.01 each) remaining significant predictors. Notably, not achieving the blood pressure <140/90 quality measure was associated with a higher rate of DCSI increase (IRR = 1.10), while hemoglobin A1c <9% not achieved was not significant (IRR = 1.001).

Discussion

In this national, longitudinal study, we identified the demographic, comorbidity, utilization, and quality of care factors associated with DCSI. In general, we found that DCSI increased over time and that individuals who were male, Black, Spanish-speaking, living in urban areas, or those with dual-eligible status had higher DCSI scores. Comor-

Table 2. Factors Associated with Diabetes Complications Severity Index.

Parameter	Model 1 IRR (SE)	Model 2 IRR (SE)	Model 3 IRR (SE)	Model 4 IRR (SE)
Data year (ref=2016)				
2017	1.13 (0.01)*	1.09 (0.00)*	1.10 (0.01)*	1.10 (.01)*
2018	1.22 (0.01)*	1.12 (0.01)*	1.15 (.01)*	1.15 (.01)*
2019	1.30 (0.01)*	1.11 (0.01)*	1.19 (.01)*	1.19 (.01)*
2020	1.32 (0.01)*	1.13 (0.01)*	1.19 (.01)*	1.19 (.01)*
Sex (ref=male)				
Female	0.86 (0.01)*	0.88 (0.00)*	0.84 (.00)*	0.84 (.00)*
Age group (ref=65-69)				
70-74	1.08 (0.01)*	0.90 (0.01)*	1.09 (.01)*	1.09 (.01)*
75-79	1.21 (0.01)*	0.97 (0.01)*	1.21 (.01)*	1.25 (.01)*
80-84	1.34 (0.01)*	0.88 (0.01)*	1.34 (.01)*	1.38 (.01)*
85-89	1.47 (0.02)*	0.94 (0.01)*	1.45 (.01)*	1.50 (.02)*
90+	1.49 (0.02)*	0.82 (0.01)*	1.46 (.02)*	1.51 (.02)*
Race/Ethnicity (ref=white)				
Black	1.06 (0.01)*	1.04 (0.01)*	1.08 (.01)*	1.08 (.01)*
Other	0.86 (0.02)*	0.95 (0.02)*	0.93 (.02)*	0.93 (.02)*
Asian	0.78 (0.02)*	0.93 (0.02)*	0.88 (.02)*	0.89 (.02)*
Hispanic	0.94 (0.02)*	0.99 (0.02)	0.98 (.02)	0.98 (.02)
Native American	1.08 (0.07)	1.05 (0.05)	1.02 (.06)	1.02 (.06)
Primary language spoken (ref=English)				
Spanish	1.02 (0.02)	0.98 (0.01)	1.04 (.02)*	1.04 (.02)*
Other	0.95 (0.01)*	0.99 (0.01) *	0.99 (.01)*	0.99 (.01)*
Dually eligible (ref=no)				
Yes	1.26 (0.01)*	1.07 (0.01)*	1.06 (.01)*	1.06 (.01)*
Rural residence (ref=no)				
Yes	0.90 (0.01) *	0.95 (0.01) *	0.91 (.01)*	0.92 (.01)*
Charlson Comorbidity Index	-	1.18 (0.00) *		
Functional Comorbidity Index	-	1.08 (0.00) *		
Last risk score: Medicare Advantage	-	-	1.10 (.00)*	1.11 (.00)*
Last risk score: Prescription	-	-	1.09 (.00)*	1.09 (.00)*
Total count: Annual emergency department claims	-	-	1.01 (.00)*	1.01 (.00)*
Total count: Annual urgent care claims	-	-	1.01 (.00)*	1.01 (.00)*
Total count: Annual outpatient claims	-	-	1.003 (.00)*	1.003 (.00)*
Total count: Annual physician visit claims	-	-	1.003 (.00)*	1.003 (.00)*
Total count: Annual inpatient admit claims	-	-	1.07 (.00)*	1.07 (.00)*
Total count: Annual pharmacy claims	-	-	1.003 (.00)*	1.003 (.00)*
Blood pressure < 140/90 quality measure not achieved	-	-		1.10 (.01)*
Hemoglobin A1c < 9% quality measure not achieved	-	-		1.001 (.01)

* $p < 0.05$
IRR = incidence rate ratio
SE = standard error

bidities also affected DCSI; a one-point increase in CCI was associated with an 18% increase in DCSI. From the perspective of utilization and quality, higher predicted prescription drug costs, emergency department claims, and not achieving guideline-recommended blood pressure levels were associated with higher DCSI. In contrast, those who identified as Hispanic or lived in rural areas had lower DCSIs. The relationship between age and DCSI was mixed. In the first model, older age was associated with higher DCSI, but these two variables were inversely related when accounting for other covariates. After controlling for comorbidities in model 2, for example, we hypothesize that individuals who have reached older ages may benefit from unmeasured genetic, behavioral, and social factors that are protective. This relationship should be studied in different populations to determine whether it is reproducible. In general, our findings validate and add to the results of others. Like us, others found that more comorbidities,¹⁶ rising age,³² and minoritized populations^{17,19} had higher DCSIs. These findings have important implications for the primary care clinicians delivering holistic, person-centered diabetes care.³³

For example, improving quality in primary care could prevent complications, though our findings were mixed. Over the past two decades, there has been a push to transform our healthcare system to one that rewards value rather than volume. As a result, systems dedicated to recording, improving, and reporting the quality measures that drive value have emerged, representing a massive investment that costs primary care practices over \$65,000 annually.³⁴ Our research found that one quality measure (blood pressure control) was associated with lower DCSI. This relationship is supported by decades of evidence demonstrating that improved blood pressure control can reduce the incidence of heart disease, strokes, and kidney disease.^{35,36} Furthermore, other factors may explain why improved blood pressure control protects against the accumulation of diabetes complications. For instance, the ability to meet this quality metric may reflect well-resourced primary care practices with the processes (like electronic health record alerts) and people (like dietitians) needed to control chronic conditions systematically. Additionally, the patients who visit these practices may experience lower barriers to access, live in less impoverished neighborhoods, and have money to pay for the medications, supplies, food, tests, and specialists needed to manage diabetes mellitus effectively.

Paradoxically, meeting the quality measure for diabetes control was not associated with lower DCSI. Despite the investment in quality improvement, rates of amputations and end-stage renal disease remain stubbornly high.³⁷ These trends suggest that systems to improve quality have had an inconsistent and inadequate effect. Alternatively, our finding could be a function of when we assessed the quality measure (2016-2019). Measurements in these years represent diabetes control at one point in time and may not be

representative of control throughout the study period. For example, a patient who did not meet the quality measure in 2019 may have made changes that reduced their hemoglobin A1c in 2020. Furthermore, hemoglobin A1c is a surrogate marker strongly tied to but distinct from the complications that ultimately lead to worse health.²⁶ While early optimization of glucose has been shown to reduce long-term complications from diabetes,^{7,36,38} not all interventions that lower hemoglobin A1c translate into improved clinical outcomes. This discrepancy has led some to question the test's utility as a quality measure.³⁹ Similar to our other findings, this relationship should be studied in different populations.

Researchers can use these findings to better risk stratify patients. For example, separate groups have developed tools to predict complications using data from the United Kingdom Prospective Diabetes Study⁴⁰ and the Action to Control Cardiovascular Risk in Diabetes Study (Risk Equations for Complications of type 2 Diabetes).⁴¹ To date, no tools predict changes in DCSI. Risk stratification is critical to treatment paradigms for conditions like cardiovascular disease, where risk determines individuals should receive cholesterol-lowering medication.⁴² The effective pairing of risk and treatment was cited as a factor responsible for declines in cardiovascular mortality.⁴³ For diabetes mellitus, the status quo is that treatment is intensified only after poor outcomes (e.g., high hemoglobin A1c or the emergence of a complication) appear. To reduce complications, a more proactive approach is needed.

Several limitations should be considered when interpreting these results. First, while our cohort is national, it comes from a single insurer. Our results may differ if we included uninsured individuals. Second, because age affects access to Medicare and the natural course of diabetes mellitus, we only included individuals aged 65 and older. Thus, our results may need to be more generalizable to younger individuals. Third, we did not include covariates that affect DCSI, like specific medications and lab results. Social risk factors, including housing, food, loneliness, and neighborhood characteristics, can similarly influence diabetes control but were omitted. We did not include quality measures for microalbumin or cholesterol as these were either retired or modified during the study period. These will be assessed in future papers. Finally, the ICD-10 codes we used to generate DCSI scores have known limitations. For example, the accuracy of these codes is dependent on clinician documentation, financial incentives to code maximally, and access to care, all of which can lead to false positives (e.g., the patient does not have the coded complication) and false negatives (e.g., the patient has a complication that was not coded). We did not assume that complications persisted because we could not distinguish between the resolution of complications and coding oversights. If a complication was coded in one year but not in a subsequent one, the complication was not carried forward, which may underestimate DCSI. This may be particularly impactful in areas with low

access, like rural communities. Other methods for capturing complications, such as checklists, have the potential to improve accuracy but are more time-consuming and, thus, less scalable.

Our findings reveal that comorbidities, Black race, prescription drugs, and emergency department visits are associated with increased DCSI. In contrast, rural residence and blood pressure control are linked to lower DCSI. Given the high incidence of complications, these results highlight the critical need for targeted interventions and proactive risk stratification to mitigate the health and financial burdens of diabetes complications. Future research should investigate the contribution of additional factors and validate these findings in diverse populations.

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Conflicts of Interest

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Guarantor

O.A. had full access to all the study data and is responsible for its integrity and the accuracy of the data analysis.

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