

Heterogeneous 30-Day Readmission Risk in Diabetic Kidney Disease: A Nationwide Analysis Stratified by Phenotype, Age, and Socioeconomic Status

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Abstract

Background

Diabetic kidney disease (DKD) carries substantial hospital readmission burden. We characterized 30-day readmission patterns following DKD hospitalization, with stratified analyses by phenotype, age, and social determinants of health (SDOH).

Methods

Using the 2018 Nationwide Readmissions Database (NRD) with complex survey-weighted analyses (DISCWT), we identified adult index hospitalizations with a principal DKD diagnosis (January–November 2018). Survey-weighted multivariable logistic regression and Wald interaction tests identified independent readmission predictors.

Results

Among 1,291,033 index hospitalizations (weighted estimate ~ 2.37 million), the 30-day all-cause readmission rate was 15.96% (95% CI: 15.78%–16.14%), significantly higher for type 1 than type 2 DKD (22.42% vs. 15.69%; $p < 0.001$). Non-DKD systemic diagnoses accounted for 91.97% of readmissions. Type 1 DKD exhibited a pronounced inverse age–readmission gradient (28.8% in patients < 40 years to 15.2% in those > 79 years; age $\times$ phenotype interaction $p = 9.3 \times 10^{-14}$). The strongest independent predictors were ESRD (aOR 1.591), heart failure (aOR 1.348), anemia (aOR 1.208), COPD (aOR 1.194), and type 1 DKD status (aOR 1.288; all $p < 0.001$). Medicaid insurance independently predicted higher readmission risk (aOR 1.037; 95% CI: 1.007–1.069; $p = 0.016$). Model discrimination was modest (C-statistic: 0.61).

Conclusions

Readmission risk in DKD is heterogeneous across diabetes phenotype, age, and socioeconomic strata, driven predominantly by non-DKD systemic comorbidities. Medicaid reliance and low income independently worsen outcomes, underscoring the critical role of SDOH in guiding targeted transitional care.

Introduction

Diabetic kidney disease (DKD) is a frequent and serious long-term complication of both type 1 and type 2 diabetes mellitus, and represents the leading cause of chronic kidney disease (CKD) and end-stage renal disease (ESRD) requiring dialysis or transplantation in the United States and globally [1]. Approximately 30%–40% of patients with diabetes will develop DKD over their lifetime [2]. The prevalence of DKD

continues to rise, driven by the expanding diabetes epidemic, improved survival among diabetic patients, and a growing cohort of younger individuals with the disease [3]. Although DKD has become a major contributor to hospitalization burden, the determinants and patterns of short-term readmission in this population remain incompletely characterized. Existing studies mainly evaluated overall readmission burden or selected comorbidities, with limited distinction between type 1 and type 2 DKD phenotypes and insufficient evaluation of how age and socioeconomic factors modulate readmission risk [4].

Disease progression is closely coupled with escalating healthcare expenditures spanning inpatient admissions, outpatient management, and pharmacological therapy [5]–[6]. Among these cost drivers, hospital readmissions—particularly within 30 days of discharge—have emerged as a critical indicator of care quality and a primary target for cost containment [7]. Reported readmission rates in DKD range from 12.8% to 27.2% at 90 days, and may exceed 50% within one year [6]. Given the scale and preventability of these readmissions, identifying risk factors and characterizing high-risk patient subgroups are essential steps toward reducing unnecessary healthcare utilization [8].

Despite growing recognition of this burden, important evidence gaps persist. Type 1 and type 2 DKD differ in pathophysiology, age of onset, comorbidity profile, and socioeconomic context, yet prior readmission studies have rarely distinguished between these phenotypes. Furthermore, the degree to which age and socioeconomic factors—including insurance status and household income—modify readmission risk across DKD phenotypes has not been systematically examined [10]–[11]. Understanding these sources of heterogeneity is essential for identifying patient groups at disproportionate readmission risk and informing targeted preventive strategies.

To address these questions, we analyzed the 2018 Nationwide Readmissions Database (NRD)—a large, nationally representative cohort encompassing both insured and uninsured patients—to characterize 30-day readmission patterns following DKD hospitalization, with stratified analyses across age, sex, and socioeconomic domains, and with explicit distinction between type 1 and type 2 DKD phenotypes. Readmission causes were classified into DKD-specific, other diabetes-related comorbidity, and non-diabetes-related categories according to the principal readmission diagnosis; findings of cause attribution should therefore be interpreted as administrative classifications rather than mechanistic disease pathways.

Materials and Methods

Data Source and Ethical Considerations

This retrospective cohort study utilized the 2018 Nationwide Readmissions Database (NRD), developed by the Healthcare Cost and Utilization Project (HCUP). The NRD contains approximately 17.7 million discharge records from 28 geographically diverse states and employs a unique patient linkage number (NRD_VisitLink) to enable tracking of repeat hospitalizations within the same state over a calendar year. Because this study used de-identified, publicly available administrative data under the HCUP Data Use

Agreement [12], it was exempt from Institutional Review Board approval and the requirement for informed consent, in accordance with the ethical principles of the Declaration of Helsinki.

Study Population

Index hospitalizations were identified from January 1 to November 30, 2018, among adults with a discharge diagnosis of diabetic kidney disease (DKD) based on ICD-10-CM codes E10.21, E10.22, E11.21, or E11.22 in any diagnostic field. December admissions were excluded to ensure complete 30-day follow-up. Additional exclusion criteria were: (1) age < 18 years or pregnancy; (2) in-hospital death during the index admission; and (3) missing key demographic or survey design variables. The final analytic cohort comprised 1,291,033 index hospitalizations and was stratified into type 1 DKD (E10.21, E10.22) and type 2 DKD (E11.21, E11.22). All comorbidities and covariates were ascertained from index discharge diagnosis codes, reflecting conditions present at or recorded during the index hospitalization rather than confirmed antecedent diagnoses. A complete list of ICD-10-CM codes used for comorbidity identification is provided in Supplementary Table S2.

Outcomes and Exposure Classification

The primary outcome was all-cause unplanned readmission within 30 days of index discharge, ascertained via NRD_VisitLink linkage. The primary exposure was DKD type (type 1 vs. type 2). Readmissions were classified into three mutually exclusive categories based on the principal diagnosis field (I10_DX1) of the readmission record, which under the HCUP coding hierarchy reflects the chief reason for inpatient admission: (1) DKD-specific readmissions (E10.21, E10.22, E11.21, or E11.22 as principal readmission diagnosis); (2) other diabetes mellitus (DM)-related comorbidity readmissions (other E10.x or E11.x codes as principal diagnosis, excluding DKD-specific codes); and (3) non-DM readmissions (all other principal diagnoses). Subcategories within each readmission class were defined per Supplementary Table S2.

Covariates

Covariates included age group (six categories: <40, 40–49, 50–59, 60–69, 70–79, > 79 years), sex, primary insurance type (Medicare, Medicaid, private, self-pay/other), median household income quartile, hospital urbanicity (NCHS six-level classification), discharge disposition, and elective admission status. Comorbidities were identified from index hospitalization discharge codes (Supplementary Table S2) and included: ESRD, heart failure, anemia, COPD, DKA, malignancy, CAD, stroke/TIA, PVD, hyperlipidemia, obstructive sleep apnea, NAFLD/NASH, sepsis, depression/anxiety, and tobacco use.

Statistical Analysis

All analyses incorporated the NRD complex survey design to generate nationally representative estimates: discharge weights (DISCWT), hospital-level clustering (HOSP_NRD), and stratification (NRD_STRATUM), per AHRQ analytic guidelines. Survey-weighted proportions are reported throughout. Covariate balance between type 1 and type 2 DKD was assessed using standardized mean differences (SMD), with $SMD \geq 0.10$ indicating meaningful imbalance (Supplementary Figure S1). Given the large sample size ($N = 1,291,033$), p-values for descriptive comparisons are not reported, as clinically trivial differences routinely achieve statistical significance at this scale.

Survey-weighted multivariable logistic regression models (svyglm, quasibinomial family, R survey package version 4.2) were used to estimate adjusted odds ratios (aORs) and 95% confidence intervals (CIs) for the association between covariates and 30-day readmission. Separate models were fitted for all-cause, other DM-related, and non-DM readmission outcomes; DKD-specific readmission was not modeled due to insufficient type 1 DKD event counts. All prespecified covariates were retained in the final models regardless of statistical significance. To control the family-wise false discovery rate across all model terms, p-values were adjusted using the Benjamini–Hochberg (BH) procedure; adjusted $p < 0.05$ was considered statistically significant.

Subgroup analyses were performed by fitting separate svyglm models within strata defined by age group, insurance type, and median household income quartile; the stratifying variable was excluded from the covariate set within its corresponding stratum. Interaction p-values were derived from survey-weighted Wald F-tests comparing the type 1 vs. type 2 DKD aOR across strata. BH correction was applied across all subgroup comparisons.

Model discrimination was assessed using the survey-weighted C-statistic (equivalent to the area under the ROC curve), with 95% confidence intervals derived from 1,000 cluster-level bootstrap iterations (resampling at the hospital level). Calibration was assessed via the calibration slope (observed outcome regressed on log-odds predicted probability); a slope of 1.0 indicates perfect calibration. E-value analyses were performed to assess the robustness of primary associations to potential unmeasured confounding (Supplementary Figure S2), following the method of VanderWeele and Ding (2017) [13]. All analyses were conducted in R (version 4.4.0; R Foundation for Statistical Computing, Vienna, Austria) using the survey package (version 4.2).

Results

Baseline Characteristics

The final analytic cohort comprised 1,291,033 index hospitalizations, representing a nationally weighted estimate of 2,367,585 discharges. Type 2 DKD accounted for 96.15% of the cohort ($n = 1,241,372$; weighted $N = 2,273,085$), while type 1 DKD comprised 3.85% ($n = 49,661$; weighted $N = 94,501$). The two phenotypes were distinct in demographic profile. Type 1 DKD patients were younger (weighted median age 49 [IQR 37–63] years vs. 71 [IQR 62–80] years; $SMD = 1.37$), and nearly half were under age 40

(31.3%), compared with only 1.4% of type 2 DKD patients (Table 1). Diabetic ketoacidosis (DKA) was more prevalent in type 1 DKD (19.79% vs. 1.11%; SMD = 0.66), whereas comorbidities including COPD (23.48% vs. 10.19%; SMD = 0.37), hyperlipidemia (55.47% vs. 43.57%; SMD = 0.26), and obstructive sleep apnea (17.29% vs. 9.91%; SMD = 0.23) were more common in type 2 DKD. ESRD prevalence was high and comparable between phenotypes (78.99% vs. 79.86%; SMD = 0.07). Medicare was the predominant insurer overall (77.60%), though Medicaid coverage was higher in type 1 DKD (20.42% vs. 8.46%; SMD = 0.36), consistent with its younger age distribution. Full baseline characteristics and comorbidity profiles are presented in Table 1.

Table 1

Baseline characteristics and comorbidities of patients with diabetic kidney disease, categorized by DKD type.

Variables	Overall	Type 1 DKD	Type 2 DKD	SMD
Unweighted N	1,291,033	49,661	1,241,372	
Weighted N	2,367,585	94,501	2,273,085	
Demographics				
Age (years, [IQR])	71 [61,79]	49 [37,63]	71 [62,80]	1.37
Age groups (%)				
<40 years	33,227 (2.57)	15,530 (31.27)	17,697 (1.43)	0.89
40–49 years	66,692 (5.17)	9,480 (19.09)	57,212 (4.61)	0.46
50–59 years	173,783 (13.46)	9,216 (18.56)	164,567 (13.25)	0.14
60–69 years	318,642 (24.68)	7,953 (16.01)	310,689 (25.03)	0.24
70–79 years	380,463 (29.46)	4,998 (10.06)	375,465 (30.25)	0.52
>79 years	318,226 (24.65)	2,484 (5.00)	315,742 (25.43)	0.60
Sex (%)				
Female	596,693 (46.22)	24,150 (48.63)	572,543 (46.12)	0.04
Primary insurance type (%)				
Medicare	1001,849 (77.60)	28,637 (57.66)	973,212 (78.40)	0.48
Medicaid	115,099 (8.92)	10,139 (20.42)	104,960 (8.46)	0.36
Private	135,746 (10.51)	8,797 (17.71)	126,949 (10.23)	0.22
Self-pay	14,283 (1.11)	1,229 (2.47)	13,054 (1.05)	0.11
No charge and Other	24,056 (1.86)	859 (1.73)	23197 (1.87)	0.14
Table footnote:				
Unweighted N represents the actual number of discharge records. Weighted N represents national estimates generated using NRD discharge weights (DISCWT). Percentages are survey-weighted estimates accounting for clustering (HOSP_NRD) and stratification (NRD_STRATUM). Continuous variables are presented as weighted median [interquartile range (IQR)], and categorical variables as weighted percentages. Standardized mean differences (SMD) compare type 1 versus type 2 DKD; SMD ≥ 0.10 indicates meaningful imbalance. P-values are not reported given the large sample size (N = 1,291,033), in which clinically trivial differences routinely achieve statistical significance.				

Variables	Overall	Type 1 DKD	Type 2 DKD	SMD
Median household income (%)				
<\$45,999	400,872 (31.05)	15,168 (30.54)	385,704 (31.07)	0.01
\$46k-\$59k	364,909 (28.26)	14,226 (28.65)	350,683 (28.25)	0.01
\$59k-\$79k	305,498 (23.66)	12,017 (24.20)	293,481 (23.64)	0.01
≥\$79k	219,754 (17.02)	8,250 (16.61)	211,504 (17.04)	0.02
Discharge Status (%)				
Routine discharge	571,079 (45.78)	30,246 (60.90)	560,833 (45.18)	0.04
Short-term hospital	14,217 (1.10)	478 (0.96)	13,739 (1.11)	0.004
SNF,ICF or other	341,276 (26.43)	7,720 (15.55)	333,556 (26.87)	0.03
Home health care	326,717 (25.30)	9,474 (19.08)	317,243 (25.56)	0.03
Against medical advice	17,382 (1.35)	1,735 (3.49)	15,647 (1.26)	0.002
Destination unknown	362 (0.03)	8 (0.02)	354 (0.03)	0.03
Patient Location (%)				
Large central metro	394,864 (30.59)	13,966 (28.12)	380,898 (30.68)	0.04
Large fringe metro	322,898 (25.01)	12,629 (25.40)	310,269 (24.99)	0.004
Medium metro	278,204 (21.55)	11,495 (23.14)	266,709 (21.49)	0.03
Small metro	119,879 (9.29)	4,966 (10.00)	114,913 (9.26)	0.03
Micropolitan	98,480 (7.63)	3,870 (7.79)	94,610 (7.62)	0.02
Non-core (rural)	76,708 (5.94)	2,735 (5.51)	73,973 (5.96)	0.03
Other comorbidities (%)				
Table footnote:				
Unweighted N represents the actual number of discharge records. Weighted N represents national estimates generated using NRD discharge weights (DISCWT). Percentages are survey-weighted estimates accounting for clustering (HOSP_NRD) and stratification (NRD_STRATUM). Continuous variables are presented as weighted median [interquartile range (IQR)], and categorical variables as weighted percentages. Standardized mean differences (SMD) compare type 1 versus type 2 DKD; SMD ≥ 0.10 indicates meaningful imbalance. P-values are not reported given the large sample size (N = 1,291,033), in which clinically trivial differences routinely achieve statistical significance.				

Variables	Overall	Type 1 DKD	Type 2 DKD	SMD
Diabetic neuropathy	144,908 (11.22)	8,563 (17.42)	136,345 (10.98)	0.18
Diabetic foot ulcer	71,956 (5.57)	4,749 (9.56)	67,207 (5.41)	0.18
Diabetic retinopathy	6,873 (0.53)	553 (1.11)	6,320 (0.51)	0.07
DKA	23,638 (1.83)	9,828 (19.79)	13,810 (1.11)	0.66
ESRD	1,020,174 (79.02)	39,672 (79.86)	980,502 (78.99)	0.07
CAD	168,154 (13.02)	6,229 (12.54)	161,925 (13.04)	0.11
Heart Failure	116,375 (9.01)	3,376 (6.80)	112,999 (9.10)	0.37
COPD	296,481 (22.96)	5,062 (10.19)	291,419 (23.48)	0.37
Pneumonia	117,604 (9.11)	3,530 (7.11)	114,074 (9.19)	0.08
Hyperlipidemia	710,190 (55.01)	21,637 (43.57)	688,553 (55.47)	0.26
NAFLD	13,467 (1.04)	424 (0.85)	13,043 (1.05)	0.05
Metabolic syndrome	4,346 (0.34)	118 (0.24)	4,228 (0.34)	0.02
Sleep apnea syndrome	219,570 (17.01)	4,923 (9.91)	214,647 (17.29)	0.23
Electrolyte disturbances	599,365 (46.43)	27,226 (54.82)	572,139 (46.09)	0.18
Anemia	408,403 (31.63)	19,899 (40.07)	388,504 (31.30)	0.13
Depression/Anxiety	134,664 (10.43)	7,110 (14.32)	127,554 (10.28)	0.12
Tobacco use (%)	2,834 (0.22)	77 (0.16)	2,757 (0.22)	0.19
Table footnote:				
Unweighted N represents the actual number of discharge records. Weighted N represents national estimates generated using NRD discharge weights (DISCWT). Percentages are survey-weighted estimates accounting for clustering (HOSP_NRD) and stratification (NRD_STRATUM). Continuous variables are presented as weighted median [interquartile range (IQR)], and categorical variables as weighted percentages. Standardized mean differences (SMD) compare type 1 versus type 2 DKD; SMD ≥ 0.10 indicates meaningful imbalance. P-values are not reported given the large sample size (N = 1,291,033), in which clinically trivial differences routinely achieve statistical significance.				

Abbreviations: DKD, diabetic kidney disease; ESRD, end-stage renal disease; DKA, diabetic ketoacidosis; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; NAFLD, non-alcoholic fatty liver disease; SNF, skilled nursing facility; ICF, intermediate care facility; IQR, interquartile range; SMD, standardized mean difference; NRD, Nationwide Readmissions Database.

30-Day Readmission Burden

The survey-weighted 30-day all-cause readmission rate was 15.96% for the overall cohort, with a significantly higher rate among type 1 DKD patients compared with type 2 (22.42% vs. 15.69%; Table 2). The 30-day out-of-hospital mortality rate was low (0.03%), with no meaningful difference between phenotypes.

Table 2
30-day readmission outcomes and causes among DKD patients by DKD type.

Outcome	Total	Type 1 DKD	Type 2 DKD
All patients	1,291,033	49,661	1,241,372
30-Day outside hospital deaths (%)	363 (0.03)	8 (0.02)	355 (0.03)
30-Day readmissions			
All 30-day readmissions (%)	206,995 (15.96)	11,137 (22.42)	195,858 (15.69)
DKD readmissions (% of all readmissions)	1,027 (0.49)	192 (1.72)	835 (0.42)
Other DM-related complications readmissions (%)	15,588 (7.55)	3,375 (30.25)	12,213 (6.20)
DKA	2,558 (16.94)	1,541 (45.79)	1,017 (8.58)
DM with hypoglycemia	2,140 (13.68)	279 (8.68)	1,861 (15.13)
DM with hyperglycemia	1,307 (8.53)	337 (10.25)	970 (8.04)
Diabetic peripheral angiopathy	3,420 (21.53)	183 (5.27)	3,237 (26.25)
Diabetic foot ulcer	1,345 (8.54)	93 (3.60)	1,252 (10.29)
Diabetic neuropathy	2,085 (13.58)	747 (21.85)	1,338 (11.18)
DM with other specified complications	1,630 (10.48)	120 (3.73)	1,510 (12.44)
Unspecified complications and others	648 (3.78)	75 (0.83)	573 (4.63)
Non-diabetes-related complications readmissions (%)	190,380 (91.95)	7,570 (68.03)	182,810 (93.38)
Pneumonia	5,688 (3.46)	224 (3.52)	5,464 (3.45)
COPD	2,834 (1.83)	23 (0.36)	2,811 (1.89)
Respiratory failure	4,919 (2.55)	191 (2.06)	4,728 (2.58)
NSTEMI	5,624 (2.88)	220 (2.86)	5,404 (2.88)
Heart failure	1,499 (0.76)	41 (0.46)	1,458 (0.77)

Table footnote:

Values are presented as unweighted event counts with weighted proportions where applicable. Readmission rates were estimated using survey weights to generate nationally representative estimates. Percentages for "All 30-day readmissions" are calculated as a proportion of all patients. Percentages for "DKD readmissions," "Other DM-related complications readmissions," and "Non-diabetes-related complications readmissions" are calculated as a proportion of all 30-day readmissions within the corresponding DKD type. Subcategory percentages (e.g., DKA under Other DM-related; Pneumonia under Non-diabetes-related) are calculated as a proportion of their respective parent readmission category.

Outcome	Total	Type 1 DKD	Type 2 DKD
Hypertensive heart and kidney disease	34,049 (17.86)	799 (10.71)	33,250 (18.17)
UTI	2,589 (1.35)	67 (0.89)	2,522 (1.37)
Kidney failure	11,657 (6.25)	436 (6.00)	11,221 (6.26)
Hepatic failure	1,942 (0.93)	23 (0.26)	1,919 (0.96)
Sepsis	18,654 (9.52)	854 (11.15)	17,800 (9.45)
Others non-diabetes-related comorbidities	80,758 (42.42)	4,317 (57.03)	76,441 (41.81)

Table footnote:

Values are presented as unweighted event counts with weighted proportions where applicable. Readmission rates were estimated using survey weights to generate nationally representative estimates. Percentages for "All 30-day readmissions" are calculated as a proportion of all patients. Percentages for "DKD readmissions," "Other DM-related complications readmissions," and "Non-diabetes-related complications readmissions" are calculated as a proportion of all 30-day readmissions within the corresponding DKD type. Subcategory percentages (e.g., DKA under Other DM-related; Pneumonia under Non-diabetes-related) are calculated as a proportion of their respective parent readmission category.

Abbreviations: DKD, diabetic kidney disease; DM, diabetes mellitus; DKA, diabetic ketoacidosis; COPD, chronic obstructive pulmonary disease; NSTEMI, non-ST-elevation myocardial infarction; UTI, urinary tract infection.

Of 206,995 total readmissions, 91.95% were classified as non-diabetes-related based on principal readmission diagnosis. This classification reflects the primary billed diagnosis code rather than the underlying pathophysiological driver of hospital return, and should be interpreted accordingly. The leading non-DM principal diagnoses included hypertensive heart and chronic kidney disease (17.86%), sepsis (9.52%), and kidney failure (6.25%). DKD-specific readmissions (principal diagnosis E10.21, E10.22, E11.21, or E11.22) accounted for 0.49% of all readmissions, with markedly higher rates in type 1 DKD (1.72% vs. 0.42%).

Other DM-related comorbidity readmissions constituted 7.55% of all readmissions, with a disparity between phenotypes (30.25% in type 1 DKD vs. 6.20% in type 2 DKD). DKA was the dominant etiology in type 1 DKD (45.79% of other-DM readmissions vs. 8.58% in type 2 DKD), whereas diabetic peripheral angiopathy (26.25%) and hypoglycemia (15.13%) predominated in type 2 DKD. Full readmission cause distributions are presented in Table 2.

Age-Stratified Readmission Patterns

Type 1 DKD patients had higher readmission rates than type 2 across all age strata (Fig. 2A). The readmission risk associated with type 1 DKD was most pronounced in the youngest patients: in the < 40-

year age group, the weighted readmission rate was 28.8% for type 1 vs. 19.7% for type 2 (aOR 1.594, 95% CI 1.482–1.714), attenuating with age to aOR 1.146 (95% CI 1.009–1.302) among patients > 79 years (Table 4; interaction $p = 9.28 \times 10^{-14}$). This age-modifying effect was similarly observed for other DM-related comorbidity readmissions. For non-DM readmissions, the type 1 vs. type 2 difference was significant in the youngest (< 40 years; aOR 1.175, 95% CI 1.086–1.272; Fig. 2D) and 70–79-year age groups (aOR 1.102) after FDR correction. DKD-specific readmissions could not be modeled due to insufficient type 1 DKD event counts in all age strata ($n < 10$ per group; crude unweighted rates displayed in Fig. 2B).

Socioeconomic Determinants of Readmission Disparities

Insurance type modified the association between DKD phenotype and 30-day readmission risk (interaction $p = 7.72 \times 10^{-5}$; Table 4; Fig. 3). Medicaid-insured patients had the highest readmission rates in both phenotypes (type 1: 27.0%; type 2: 18.3%) and the largest relative disparity between phenotypes (aOR 1.486, 95% CI 1.385–1.594), compared with Medicare (aOR 1.217, 95% CI 1.172–1.265) and private insurance (aOR 1.318, 95% CI 1.224–1.419). Self-pay/other-insured type 1 DKD patients faced the higher readmission rates (aOR 1.581, 95% CI 1.275–1.960), though event counts in this stratum were limited. Private insurance was associated with the lowest readmission rates across both phenotypes.

Median household income showed a significant interaction with DKD type for all-cause readmission (interaction $p = 0.035$; Table 4). Patients in the lowest income quartile (<\$45,999) had the highest readmission rates in both type 1 (24.6%) and type 2 DKD (16.2%), yielding the between-phenotype gap (aOR 1.339, 95% CI 1.266–1.415). The type 1 vs. type 2 readmission excess persisted across all income strata, with aORs ranging from 1.214 in the second quartile (\$46,000–\$58,999) to 1.313 in the highest income group ($\geq$ \$79,000), suggesting that socioeconomic disadvantage amplifies but does not fully explain the phenotype-associated readmission disparity. For DM-related comorbidity readmissions stratified by socioeconomic status, type 1 DKD patients faced more than the risk of type 2 patients (aOR range 2.45–3.32; Fig. 3B; Supplementary Table S5). Non-DM readmission disparities between phenotypes were more variable across socioeconomic strata (Fig. 3C; Supplementary Table S5).

Independent Predictors of 30-Day All-Cause Readmission

Survey-weighted multivariable logistic regression identified type 1 DKD as an independent predictor of 30-day all-cause readmission compared with type 2 DKD (aOR 1.284, 95% CI 1.245–1.324; adjusted $p < 0.001$; Table 3). Among clinical comorbidities, ESRD was the strongest predictor (aOR 1.591, 95% CI 1.562–1.622), followed by heart failure (aOR 1.348, 95% CI 1.330–1.367), malignancy (aOR 1.266, 95% CI 1.236–1.296), anemia (aOR 1.209, 95% CI 1.193–1.226), COPD (aOR 1.194, 95% CI 1.176–1.213), NAFLD/NASH (aOR 1.190, 95% CI 1.142–1.240), and CAD/MI (aOR 1.106, 95% CI 1.089–1.122). Among socioeconomic predictors, Medicaid insurance was associated with higher readmission odds relative to Medicare (aOR 1.044, 95% CI 1.013–1.076), while private insurance was protective (aOR 0.769, 95% CI 0.753–0.785). Non-core rural hospital location was associated with lower readmission odds (aOR 0.900, 95% CI 0.862–0.940).

Table 3

Survey-weighted multivariable logistic regression of predictors of 30-day all-cause readmission among hospitalized patients with diabetic kidney disease.

Variable	aOR (95% CI)	p	Adjusted p
DKD type			
Type 2 DKD	Ref	—	—
Type 1 DKD	1.288 (1.248, 1.329)	< 0.001	< 0.001
Age group			
<40 years	Ref	—	—
40–49 years	0.798 (0.760, 0.837)	< 0.001	< 0.001
50–59 years	0.767 (0.735, 0.800)	< 0.001	< 0.001
60–69 years	0.709 (0.678, 0.741)	< 0.001	< 0.001
70–79 years	0.657 (0.629, 0.688)	< 0.001	< 0.001
>79 years	0.596 (0.568, 0.624)	< 0.001	< 0.001
Sex			
Female	1.000 (0.988, 1.012)	0.983	0.983
Insurance type			
Medicare	Ref	—	—
Medicaid	1.037 (1.007, 1.069)	0.016	0.020
Private	0.769 (0.753, 0.785)	< 0.001	< 0.001
Self-pay/Other	0.824 (0.774, 0.878)	< 0.001	< 0.001
Median household income quartile			
<\$45,999	Ref	—	—
\$46k-\$59k	1.004 (0.984, 1.024)	0.723	0.768
\$59k-\$79k	0.975 (0.953, 0.998)	0.032	0.040
≥\$79k	0.986 (0.959, 1.013)	0.299	0.351
Hospital location			

Table footnote:

aOR = adjusted odds ratio from survey-weighted multivariable logistic regression (svyglm, quasibinomial family; cluster: HOSP_NRD; strata: NRD_STRATUM; weight: DISCWT). p = Wald t-test p-value. Adjusted p = Benjamini–Hochberg false discovery rate (FDR)-corrected p-value across all model terms. Survey-weighted C-statistic (AUC) = 0.61.

Variable	aOR (95% CI)	p	Adjusted p
Large central metro	Ref	—	—
Large fringe metro	1.012 (0.984, 1.041)	0.411	0.465
Medium metro	0.996 (0.961, 1.031)	0.813	0.838
Small metro	0.986 (0.941, 1.032)	0.541	0.593
Micropolitan	0.919 (0.885, 0.954)	< 0.001	< 0.001
Non-core (rural)	0.900 (0.862, 0.940)	< 0.001	< 0.001
Comorbidities			
ESRD	1.591 (1.562, 1.622)	< 0.001	< 0.001
Heart failure	1.348 (1.330, 1.367)	< 0.001	< 0.001
Anemia	1.208 (1.192, 1.224)	< 0.001	< 0.001
COPD	1.194 (1.176, 1.213)	< 0.001	< 0.001
DKA	1.060 (1.017, 1.105)	0.006	0.008
Sepsis	0.811 (0.796, 0.827)	< 0.001	< 0.001
Malignancy	1.265 (1.235, 1.295)	< 0.001	< 0.001
Hyperlipidemia	0.937 (0.924, 0.950)	< 0.001	< 0.001
Obstructive sleep apnea	0.972 (0.955, 0.988)	< 0.001	< 0.001
NAFLD	1.192 (1.144, 1.243)	< 0.001	< 0.001
CAD	1.106 (1.090, 1.123)	< 0.001	< 0.001
Stroke	0.682 (0.651, 0.715)	< 0.001	< 0.001
PVD	1.069 (1.040, 1.099)	< 0.001	< 0.001
Depression/Anxiety	1.015 (0.995, 1.035)	0.153	0.186
Tobacco use	1.039 (1.018, 1.061)	< 0.001	< 0.001
Table footnote:			
aOR = adjusted odds ratio from survey-weighted multivariable logistic regression (svyglm, quasibinomial family; cluster: HOSP_NRD; strata: NRD_STRATUM; weight: DISCWT). p = Wald t-test p-value. Adjusted p = Benjamini–Hochberg false discovery rate (FDR)-corrected p-value across all model terms. Survey-weighted C-statistic (AUC) = 0.61.			

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; DKA, diabetic ketoacidosis; ESRD, end-stage renal disease; COPD, chronic obstructive pulmonary disease; NAFLD, non-alcoholic fatty liver

disease; CAD, coronary artery disease; PVD, peripheral vascular disease; FDR, false discovery rate; Ref, reference category.

Table 4

Survey-weighted 30-day readmission rates and adjusted odds ratios for Type 1 vs Type 2 DKD, stratified by age group, insurance type, and income quartile.

Subgroup	Type 1 DKD <i>n</i> (wt%)	Weighted % (95% CI)	Type 2 DKD <i>n</i> (wt%)	Weighted % (95% CI)	aOR (95% CI)	Adjusted <i>p</i>
Overall	49,661 (4.0%)	22.4 (21.8, 23.0)	1,241,372 (96.0%)	15.7 (15.5, 15.9)	1.288 (1.248, 1.329)	< 0.001
Age group	Interaction <i>p</i> = 9.28×10^{-14}					
< 40 years	15,530 (31.3%)	28.8 (27.7, 29.9)	17,697 (1.4%)	19.7 (18.9, 20.6)	1.594 (1.482, 1.714)	< 0.001
40–49 years	9,480 (19.1%)	22.3 (21.1, 23.5)	57,212 (4.6%)	18.2 (17.8, 18.7)	1.225 (1.141, 1.314)	< 0.001
50–59 years	9,216 (18.6%)	20.1 (19.0, 21.2)	164,567 (13.3%)	17.6 (17.3, 17.9)	1.184 (1.109, 1.265)	< 0.001
60–69 years	7,953 (16.0%)	17.7 (16.7, 18.8)	310,689 (25.0%)	16.5 (16.2, 16.7)	1.119 (1.042, 1.200)	0.002
70–79 years	4,998 (10.1%)	17.3 (15.8, 18.7)	375,465 (30.2%)	15.3 (15.1, 15.5)	1.196 (1.083, 1.321)	< 0.001
> 79 years	2,484 (5.0%)	15.2 (13.6, 16.7)	315,742 (25.4%)	13.6 (13.4, 13.8)	1.146 (1.009, 1.302)	0.036
Insurance type	Interaction <i>p</i> = 7.72×10^{-5}					
Medicare	28,637 (57.7%)	22.9 (22.2, 23.6)	973,212 (78.4%)	15.9 (15.7, 16.1)	1.215 (1.170, 1.262)	< 0.001

Table footnote:

n = unweighted sample size; wt% = proportion within the corresponding DKD type group. Weighted % (95% CI) = survey-weighted 30-day readmission rate with 95% confidence interval. aOR = adjusted odds ratio for type 1 versus type 2 DKD from a separate survey-weighted logistic regression (svyglm, quasibinomial; DISCWT, HOSP_NRD, NRD_STRATUM) fit within each subgroup stratum; the stratifying variable was excluded from the covariate set within its corresponding stratum. The overall aOR is from the full-cohort model (Table 3). Adjusted *p* = Benjamini–Hochberg FDR correction across all subgroup comparisons. Interaction *p*-values derived from survey-weighted Wald F-tests comparing the T1/T2 aOR across strata.

Subgroup	Type 1 DKD n (wt%)	Weighted % (95% CI)	Type 2 DKD n (wt%)	Weighted % (95% CI)	aOR (95% CI)	Adjusted p
Medicaid	10,139 (20.4%)	27.0 (25.7, 28.2)	104,960 (8.5%)	18.3 (17.9, 18.8)	1.486 (1.385, 1.594)	< 0.001
Private	8,797 (17.7%)	16.3 (15.3, 17.3)	126,949 (10.2%)	12.8 (12.5, 13.0)	1.318 (1.224, 1.419)	< 0.001
Self-pay/Other	1,229 (2.5%)	19.8 (17.0, 22.7)	13,054 (1.1%)	14.0 (13.2, 14.8)	1.581 (1.275, 1.960)	< 0.001
Median household income					Interaction p = 0.035	
<\$45,999	15,168 (30.5%)	24.6 (23.6, 25.7)	385,704 (31.1%)	16.2 (16.0, 16.5)	1.340 (1.268, 1.416)	< 0.001
\$46k-\$59k	14,226 (28.6%)	22.0 (21.0, 23.0)	350,683 (28.2%)	15.7 (15.5, 16.0)	1.214 (1.146, 1.287)	< 0.001
\$59k-\$79k	12,017 (24.2%)	21.1 (20.0, 22.1)	293,481 (23.6%)	15.2 (15.0, 15.5)	1.284 (1.207, 1.367)	< 0.001
≥\$79k	8,250 (16.6%)	20.6 (19.4, 21.8)	211,504 (17.0%)	15.1 (14.8, 15.4)	1.312 (1.223, 1.407)	< 0.001
Table footnote:						
n = unweighted sample size; wt% = proportion within the corresponding DKD type group. Weighted % (95% CI) = survey-weighted 30-day readmission rate with 95% confidence interval. aOR = adjusted odds ratio for type 1 versus type 2 DKD from a separate survey-weighted logistic regression (svyglm, quasibinomial; DISCWT, HOSP_NRD, NRD_STRATUM) fit within each subgroup stratum; the stratifying variable was excluded from the covariate set within its corresponding stratum. The overall aOR is from the full-cohort model (Table 3). Adjusted p = Benjamini–Hochberg FDR correction across all subgroup comparisons. Interaction p-values derived from survey-weighted Wald F-tests comparing the T1/T2 aOR across strata.						

Abbreviations: DKD, diabetic kidney disease; aOR, adjusted odds ratio; CI, confidence interval; wt%, weighted percentage; FDR, false discovery rate.

Two comorbidities were associated with reduced readmission odds in the adjusted model: sepsis (aOR 0.811, 95% CI 0.796–0.826) and stroke/TIA (aOR 0.683, 95% CI 0.652–0.715). These inverse associations likely reflect survivor bias, as patients surviving these high-acuity index admissions represent a selected resilient subpopulation; for stroke patients, post-discharge disposition to long-term care facilities may additionally reduce NRD-captured readmission events. Sex was not independently

associated with all-cause readmission risk (female aOR 1.001, 95% CI 0.989–1.013; $p = 0.983$). Model discrimination was modest (survey-weighted C-statistic 0.612, 95% CI 0.608–0.616 Supplementary Table S6), consistent with the inherent heterogeneity of all-cause readmission outcomes in administrative database studies; calibration was excellent (calibration slope 1.001, 95% CI 0.987–1.015). Forest plots illustrating aORs for all predictor variables across four readmission outcome models are presented in Fig. 1 and Supplementary Table S3.

Discussion

In this nationwide analysis of 1,291,033 DKD hospitalizations, we identified four key patterns: (1) an overall 30-day readmission rate of 15.96%, disproportionately affecting type 1 DKD (22.42%); (2) a consistent inverse age gradient in both DKD phenotypes, with type 1 rates persistently exceeding type 2; (3) non-DKD systemic comorbidities accounting for approximately 92% of readmissions; and (4) independent contributions of Medicaid insurance and lower household income to readmission risk.

These age-stratified differences between DKD phenotypes likely reflect distinct underlying pathophysiology and behavioral factors. In type 1 DKD, readmission rates gradually decrease from 28.87% in patients younger than 40 years to 15.74% in those above 79 years, indicating a higher burden of readmissions among younger patients that diminishes with age. Elevated readmissions in younger type 1 DKD patients may reflect difficulties in glycemic control and increased risk of acute metabolic complications during early adulthood, supported by the high prevalence of diabetic ketoacidosis (45.79% of diabetes-specific readmissions in type 1 DKD) [14]. By contrast, type 2 DKD patients exhibit lower readmission rates in younger age groups, with rates declining steadily across all age strata. This pattern suggests a cumulative impact of chronic comorbid conditions, such as hypertensive heart and kidney disease—which accounts for a substantial proportion (17.86%) of non-DM readmission causes—driving rehospitalization risk in older adults with type 2 DKD [15]. The most pronounced between-phenotype difference occurred in patients younger than 40 years, reflecting the disproportionate burden of acute metabolic decompensation—particularly DKA—among young adults with type 1 DKD, a population with substantial insulin dependence and often suboptimal glycemic self-management [16]. With advancing age, the between-phenotype gap narrowed, though type 1 patients aged 40–49 years—who typically carry two to three decades of disease—may harbor substantial established microvascular complications accrued over that duration [17].

Furthermore, although sex was not an independent predictor of overall all-cause readmission risk in multivariable analysis (aOR 1.001, 95% CI 0.98–1.013), female patients demonstrated a modestly lower rate of other diabetes-related complication readmissions (aOR 0.932, 95% CI 0.894–0.972). Several mechanisms may explain that to these sex-specific patterns. Hormonal fluctuations in premenopausal women can affect glycemic control and may influence acute metabolic complication risk in female type 1 DKD patients. The autoimmune nature of type 1 diabetes, which typically exhibits stronger sex-based immunological differences, has been documented previously [18].

Socioeconomic Disparities in Readmission Risk

Insurance status emerged as a powerful predictor of readmission risk. Medicaid beneficiaries demonstrated higher readmission rates compared to privately insured patients. These disparities may reflect fragmented care transitions among Medicaid patients and reduced access to specialized nephrology services [19]. Within the U.S. healthcare landscape, these patients often cannot access timely nephrology follow-up within the critical 7–14 days after discharge. Financial barriers prevent timely access to emerging nephroprotective agents. It is important to note that, at the time of our study (2018), SGLT2 inhibitors and GLP-1 receptor agonists had not yet been widely adopted in DKD management, and landmark trials establishing their renoprotective benefits (e.g., CREDENCE, DAPA-CKD) were either ongoing or not yet published. The socioeconomic disparities we identify therefore likely reflect access barriers to then-established therapies—including renin–angiotensin–aldosterone system blockade, loop diuretics, and erythropoiesis-stimulating agents—which were the cornerstone of DKD care during this period [20].

Our data challenge the notion that DKD readmissions reflect primarily metabolic failures. Over 91% were driven by acute systemic events—hypertensive heart disease, sepsis, and malignancy. The shared pathophysiological substrate of DKD (systemic insulin resistance, chronic inflammation, and oxidative stress) predisposes patients to multi-organ vulnerability [21], such that early hospital return often signals systemic decompensation rather than isolated diabetes-related deterioration. It is important to interpret the high proportion of non-diabetes-related readmissions (91.97%) within the context of our study's coding methodology.

Clinical Implications

Our findings have several clinical implications: **Cardio-Renal-Metabolic (CRM) Integration:** The dominance of heart failure and sepsis as readmission drivers dictates that discharge planning cannot be rigidly glucose-centric. Rigorous pre-discharge optimization of volume status, medication reconciliation (emphasizing cardiovascular guideline-directed medical therapy), and vigilant infection surveillance are paramount [22]–[23]. **Phenotype-Targeted Transitional Care:** Risk stratification must be individualized. Young type 1 DKD patients require intensive diabetic education and affordable insulin access programs. Conversely, elderly type 2 DKD patients necessitate multidisciplinary geriatric and cardiology oversight. **Addressing the SDOH Gap:** High-risk phenotypes identified herein (e.g., Medicaid-insured, low-income patients with concomitant ESRD or anemia) should automatically trigger intensive transitional care protocols. Hospitals must integrate social workers into the nephrology pathway to overcome financial barriers to essential DKD medications and establish early telehealth or visiting-nurse follow-ups [24]. While SGLT2 inhibitors and GLP-1 receptor agonists have since emerged as transformative nephroprotective agents in subsequent years, the socioeconomic access barriers documented in this 2018 cohort are likely to have intensified rather than diminished with the introduction of these high-cost therapies, underscoring the sustained relevance of our findings.

Strengths and Limitations

The main strength of this analysis is its use of a large, nationally representative sample, which provided sufficient statistical power to examine readmission disparities across specific DKD subgroups—comparisons that would be infeasible in single-center studies [25]. Second, our specific focus on 30-day readmissions addresses a critical early post-discharge period that represents a key quality metric for healthcare systems [26]–[27]. This window corresponds to the period of greatest readmission risk and is most sensitive to deficiencies in discharge planning and medication reconciliation, distinguishing our work from studies examining longer readmission intervals that may reflect disease progression rather than transitional care deficiencies [28]–[29]. Furthermore, we specifically examined readmissions in DKD patients and distinguished between type 1 and type 2 DKD, revealing important heterogeneity in readmission patterns that has not been well-characterized.

This study has several limitations. First, the retrospective administrative database design inherently lacks clinical granularity, including laboratory values (HbA1c, eGFR trajectories, proteinuria levels), medication adherence data, and detailed social determinants of health beyond income quartiles, precluding full adjustment for unmeasured confounders. To quantify this residual confounding risk, E-values were calculated for all primary associations (Supplementary Figure S2). E-values for ESRD (2.32) and the age-phenotype interaction in the 40–49 years group (2.89) exceeded the benchmark of 2.0, indicating substantial robustness; however, the more modest E-value for Medicaid status (1.71) acknowledges that residual socioeconomic confounding cannot be entirely excluded. Second, while explicitly planned admissions were excluded, the absolute elimination of ambiguously coded elective procedures remains impossible in any administrative database study [30]. Third, the NRD lacks outpatient pharmacy data, precluding assessment of medication adherence or the impact of pharmacological management on readmission risk. Notably, our study period (2018) predates the widespread adoption of SGLT2 inhibitors and GLP-1 receptor agonists in DKD; the CREDENCE trial was published in 2019, and these agents were not yet standard of care for DKD at the time of data collection. Future studies leveraging post-2020 administrative data will be well-positioned to evaluate whether the subsequent integration of these disease-modifying therapies has altered readmission patterns in this population. Finally, the single-year follow-up window of the NRD restricts longitudinal tracking beyond 12 months, limiting inference regarding long-term readmission trajectories [31].

Conclusions

30-day readmissions in DKD are frequent, heterogeneous, and driven predominantly by cardiovascular and infectious complications rather than isolated diabetic pathology. Social determinants of health—specifically Medicaid reliance and low income—independently worsen clinical outcomes. Reducing preventable readmissions will require moving beyond glucose-centric protocols toward integrated, multidisciplinary transitional care.

Declarations

Availability of Data and Materials

These data are not available for distribution by the authors according to the Healthcare Cost and Utilization Project (HCUP) data usage agreement, but may be obtained from the Nationwide Readmissions Database (NRD) (https://www.hcupus.ahrq.gov/tech_assist/centdist.jsp) of the Healthcare Cost and HCUP site (<https://www.hcupus.ahrq.gov/db/nation/nrd/nrddbdocumentation.jsp>) by registering and applying at the HCUP site.

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Author contributions

Qimeng Zhu, conception, design, interpretation of data, writing draft; Yang Ge, interpretation of data; Tongxin Wang, data verification; Hang Dong, analysis, data verification, critical review; Menghan Liu, interpretation of data; Zihan Xu, interpretation of data; Panpan Yin, jointly supervised; Jia Liu, acquisition of data, critical review.

Conflict of Interest

The authors declared that they have no conflict of interest.

Ethics Approval Statement

We have access to the data released from the NRD 2018 database by complying with United States Agency for Healthcare Research and Quality's HCUP Data Use Agreement. This analysis was exempt from research ethics board review because existing data from NRD were used, and no additional information was collected from participants. Since the data was de-identified, written consent from the patients was waived.

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Figures

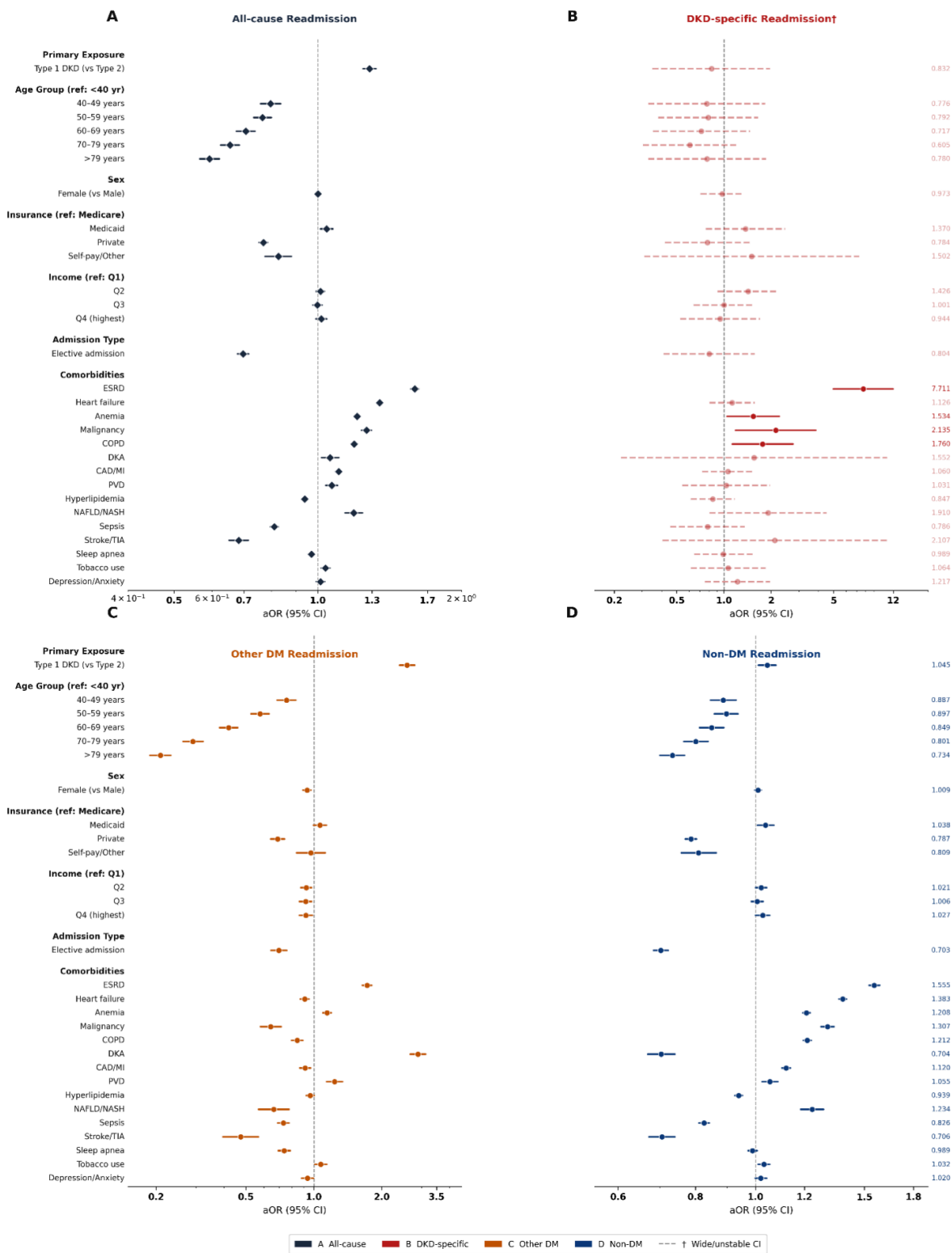


Figure 1

Main predictors of 30-day readmission in patients with type 1 and type 2 diabetic kidney disease.

Figure legend: Panels display adjusted odds ratios (aORs) and 95% confidence intervals estimated using survey-weighted logistic regression models (svyglm, quasibinomial family) accounting for discharge

weights (DISCWT), hospital clustering (HOSP_NRD), and stratification (NRD_STRATUM). Multiple testing was controlled using the Benjamini–Hochberg false discovery rate procedure.

Abbreviations: DKD, diabetic kidney disease; OR, odds ratio; DM, diabetes mellitus.

Color intensity: red (OR>1.0, increased risk), blue (OR<1.0, decreased risk).

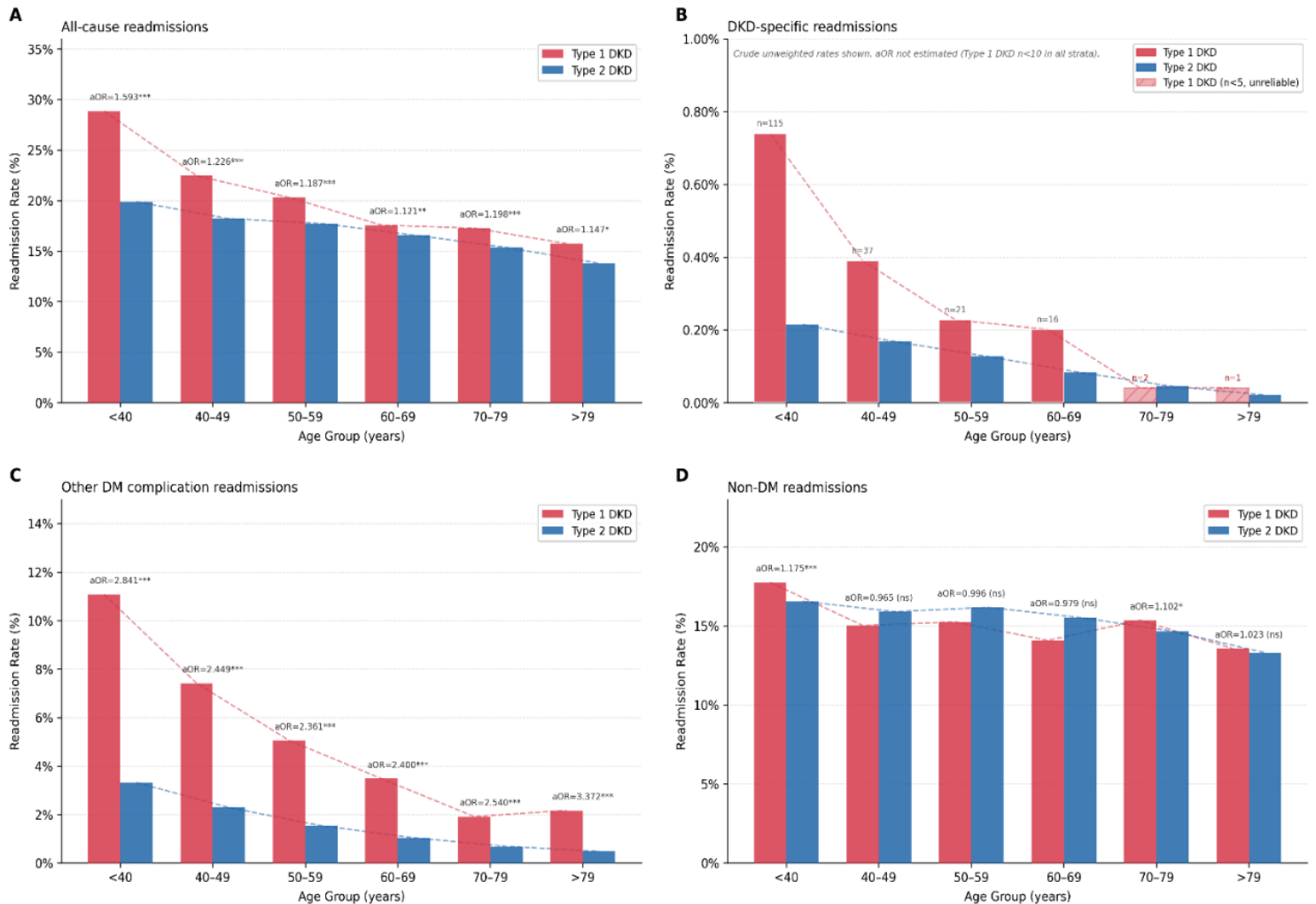


Figure 2

Survey-weighted 30-day readmission rates by age group and readmission cause among hospitalized patients with diabetic kidney disease (DKD), stratified by diabetes type.

Figure legend: (A) All-cause readmission rates. (B) DKD-specific readmissions, defined as readmissions with ICD-10-CM codes E10.x and E11.x. (C) Other diabetes mellitus (DM) complication readmissions. (D) Non-DM readmissions. Annotated adjusted odds ratios (aOR) compare type 1 versus type 2 DKD within each age stratum, estimated from age-stratified survey-weighted logistic regression models (svyglm, quasibinomial family). Significance thresholds: *p<0.05, **p<0.01, ***p<0.001; ns = not significant. P-values were adjusted using the Benjamini–Hochberg false discovery rate procedure.

Abbreviations:DKD: diabetic kidney disease; DM: diabetes mellitus; aOR: adjusted odds ratio; NRD: Nationwide Readmissions Database.

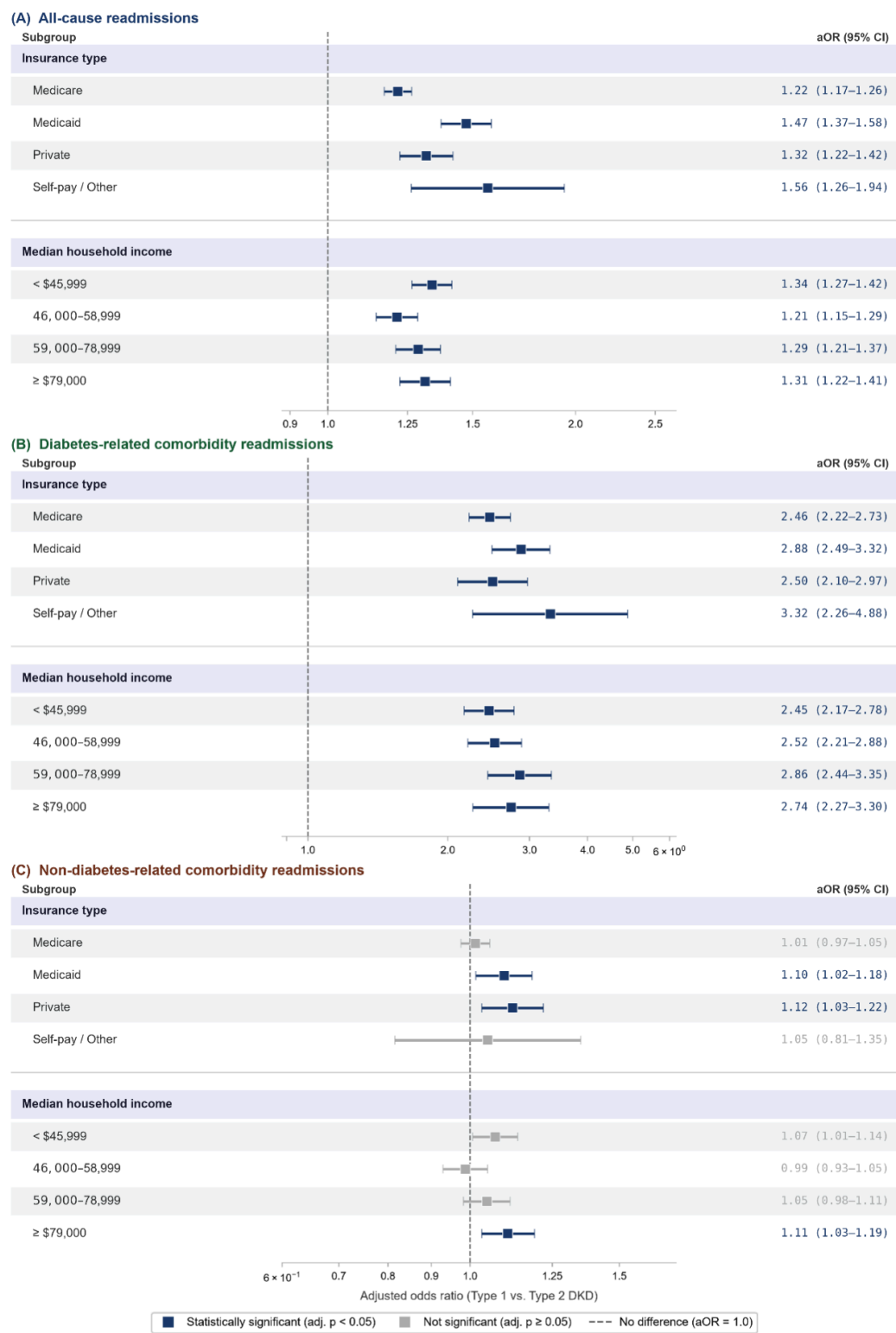


Figure 3

Survey-weighted subgroup analysis of 30-day all-cause readmission risk comparing type 1 versus type 2 diabetic kidney disease across socioeconomic strata.

Figure legend: Forest plot displaying adjusted odds ratios (aORs) with 95% confidence intervals (CIs) for 30-day readmission risk in patients with type 1 versus type 2 diabetic kidney disease (DKD), stratified by insurance type and median household income quartile. DKD-specific readmissions were not analyzed due to insufficient event counts. Estimates were derived from survey-weighted multivariable logistic regression (svyglm), incorporating discharge weights (DISCWT), hospital-level clustering (HOSP_NRD), and NRD strata (NRD_STRATUM) to generate nationally representative estimates. P-values were corrected for multiple comparisons using the Benjamini–Hochberg FDR method; adjusted $p < 0.05$ was considered statistically significant. Blue filled symbols indicate statistically significant subgroups; gray symbols indicate non-significant associations. The vertical dashed line denotes aOR = 1.0 (reference, no difference between DKD types).

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; DKD, diabetic kidney disease; NRD, Nationwide Readmissions Database.

Supplementary Files

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