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Clinical and Economic Burden of Cardiac Arrhythmias in Patients with Type 2 Diabetes

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Abstract

Importance: Cardiac arrhythmias are common in Type 2 Diabetics (T2D) and are associated with poor outcomes. Their incremental impact on Healthcare Resource Utilization (HCRU) and costs, and the effect of early detection using ambulatory Electrocardiogram (ECG) monitors, remain insufficiently characterized.

Objective: To quantify predictive factors, incremental HCRU, and costs associated with arrhythmias in T2D, and to evaluate the impact of early detection through ambulatory ECG monitoring.

Design: This population-based, retrospective cohort study used administrative claims from two US datasets: the Merative MarketScan database (2006-2023) for HCRU and total cost of care; and the Symphony Dataverse/Healthwise Consumer Data (2018-2023) for longitudinal clinical journey and risk factors analysis.

Settings: Administrative claims of insured patients acquiring care in the United States healthcare system.

Participants: Eligible patients were adults with 2 or more T2D claims less than 90 days apart, no prior claim for type 1 diabetes or COPD, and arrhythmia-naïve at T2D diagnosis. Arrhythmia cases required at least 2 arrhythmia claims. Matching was performed on age, sex, index year of arrhythmia, insurance type, comorbidity burden, and diabetes severity.

Exposures: Arrhythmia diagnosis and use of ambulatory ECG monitoring.

Main Outcome: HCRU and total cost of care.

Results: From a pool of 32 million patients with T2D, 1.19 million developed an arrhythmia (57% male, median age 71 year) and 12.3 million did not (48% male, median age 62 years). Patients who developed arrhythmias had significantly higher comorbidity burden and diabetes severity; with age over 65, hypertension, elevated DCSI, and food insecurity as the strongest predictors of arrhythmia onset. In a matched cohort (213,226 T2D patients with arrhythmias vs 213,226 patients without), those with arrhythmias had higher emergency department visits, hospitalizations, re-admissions, and healthcare costs (all p <0.001). Patients who underwent ambulatory ECG monitoring had lower HCRU and costs compared to those never monitored.

Conclusion: Among US adults with T2D, arrhythmias are associated with greater comorbidity, severity of disease, adverse social determinants of health, and substantially higher HCRU and costs. Targeted interventions for early detection, including ambulatory ECG monitoring, may mitigate this burden.

Keywords: Type 2 diabetes; Cardiac arrhythmias; Healthcare utilization; Social determinants; Outcomes research; Costs.

Introduction

Cardiac arrhythmias are increasingly recognized as significant yet underdiagnosed cardiovascular complications among individuals with Type 2 Diabetes (T2D) [1]. Despite well documented associations between T2D and arrhythmias, particularly atrial fibrillation (AF), routine arrhythmia screening is not typically incorporated into current diabetes care pathways. As a result, many arrhythmias remain undetected until the onset of serious clinical events such as stroke, heart failure, or sudden cardiac death [2-4]. The mechanistic pathways linking glycemic variability in T2D to cardiac arrhythmias involve autonomic dysfunction, electrical remodeling, oxidative stress, and inflammation [5,6].

Hypoglycemia contributes to myocardial excitability through catecholamine release, whereas chronic hyperglycemia fosters an arrhythmogenic environment *via* oxidative and inflammatory pathways [7]. Compared to the general population, individuals with T2D are 3 times more likely to have high blood pressure, 55% more likely to have experienced myocardial infarction, and 25% less likely to recognize symptoms of AF [8]. Additionally, arrhythmias in T2D are frequently underdiagnosed and often first detected during acute health events in inpatient or emergency settings, limiting opportunities for prevention and leading to higher downstream costs [2-4,9]. These missed diagnoses disproportionately affect vulnerable subgroups including older adults, racial and ethnic minorities, and individuals facing adverse social determinants of health (SDOH), exacerbating inequities in cardiovascular outcomes [10].

The American Diabetes Association (ADA) released its most recent report on the economic costs of diabetes in the U.S. in November 2023. This comprehensive analysis estimates the total annual cost of diagnosed diabetes at $412.9 billion, comprising $306.6 billion in direct medical costs and $106.3 billion in indirect costs such as lost productivity and premature mortality [11]. However, the incremental health care utilization and cost burden generated by arrhythmias, particularly silent arrhythmias, in T2D patients, remains poorly characterized. As healthcare systems transition toward value-based care, there is an urgent need to quantify arrhythmia-related outcomes and evaluate potential benefits of early detection, for example with ambulatory Electrocardiogram (ECG) monitors, to inform policymakers, payers, and clinical guideline developers.

This real-world analysis aimed to address this gap by 1) identifying predisposing demographic, clinical and social risk factors; 2) quantifying incremental Healthcare Utilization (HCRU) and costs associated with arrhythmias in T2D; and 3) assessing the impact of early detection through ambulatory ECG monitoring. These findings have implications for risk stratification, clinical guidelines development, and chronic disease management policies.

Methods

Data sources

This retrospective observational cohort study used three linked sources:

- The Symphony Integrated Dataverse (2018–2023), an open claims administrative data on more than 307 million individuals, encompassing medical and pharmacy transactions from more than 1.98 million active healthcare providers and 72,000 pharmacies, with 3.7 billion prescription claims and 1.2 billion medical transactions annually;
- Health Wise Consumer Data, which offers person-level socioeconomic insights such as education, housing, transportation, and other non-clinical risk factors using CMS Health-Related Social Needs definitions [12].
- The Merative MarketScan database (2006–2023), a closed claims database of fully adjudicated medical and pharmacy transactions for over 200 million covered lives.

All data were fully de-identified, rendering the study exempt from institutional review board review (45 CFR 46.104(d)(4)) [13].

Risk factor identification

To identify risk factors for arrhythmia among T2D, we used the Symphony Health dataset linked *vs.* Datavant tokens to Healthwise socioeconomic data and identified a national cohort of adults aged 18 years or older, during 2018-2023, with a diagnosis for T2D, (≥ 2 ICD-10 claims less than 90 days apart for E11.x) who were arrhythmia naïve at the time of this T2D diagnosis (first claim is T2D index date) (Figure 1). The target group included patients who developed a cardiac arrhythmia, defined as ≥ 2 ICD-10 claims for clinically relevant arrhythmia (based on HCC 238 and I48.x. ICD-10 codes) any time after the T2D index date. The arrhythmia index date was defined as the date of the first arrhythmia diagnosis, with all individuals having at least 12-months of data before and after this index. Patients with prior arrhythmia diagnosis, pacemakers, sick sinus syndrome, or congenital arrhythmia syndromes were excluded.

An unmatched comparator cohort of all other T2D patients without arrhythmia during the observation period was constructed to provide descriptive population level contrasts and ensure broad generalizability of findings. Patients in the comparator cohort were required to have at least 24 months of continuous history in the database and the index dates were aligned to reflect the median interval from T2D diagnosis and arrhythmia onset observed in the target group.

Descriptive comparisons were made across clinical characteristics and Social Determinants Of Health (SDOH) variables. Downstream clinical activities were compared between target and comparator groups including the use of diagnostic cardiac testing, cardiology visits, and medication classes. To further explore predictive factors for arrhythmia onset, we used mutual information to identify statistically significant differentiators and incorporated them into an XG Boost machine learning model to predict arrhythmia onset within a 6-month window. Variable importance was evaluated using SHAP (Shapley Additive Explanation) values.

Quantification of incremental healthcare utilization and costs

To quantify the incremental HCRU and costs of arrhythmia in T2D, we used the Merative MarketScan database and identified adults

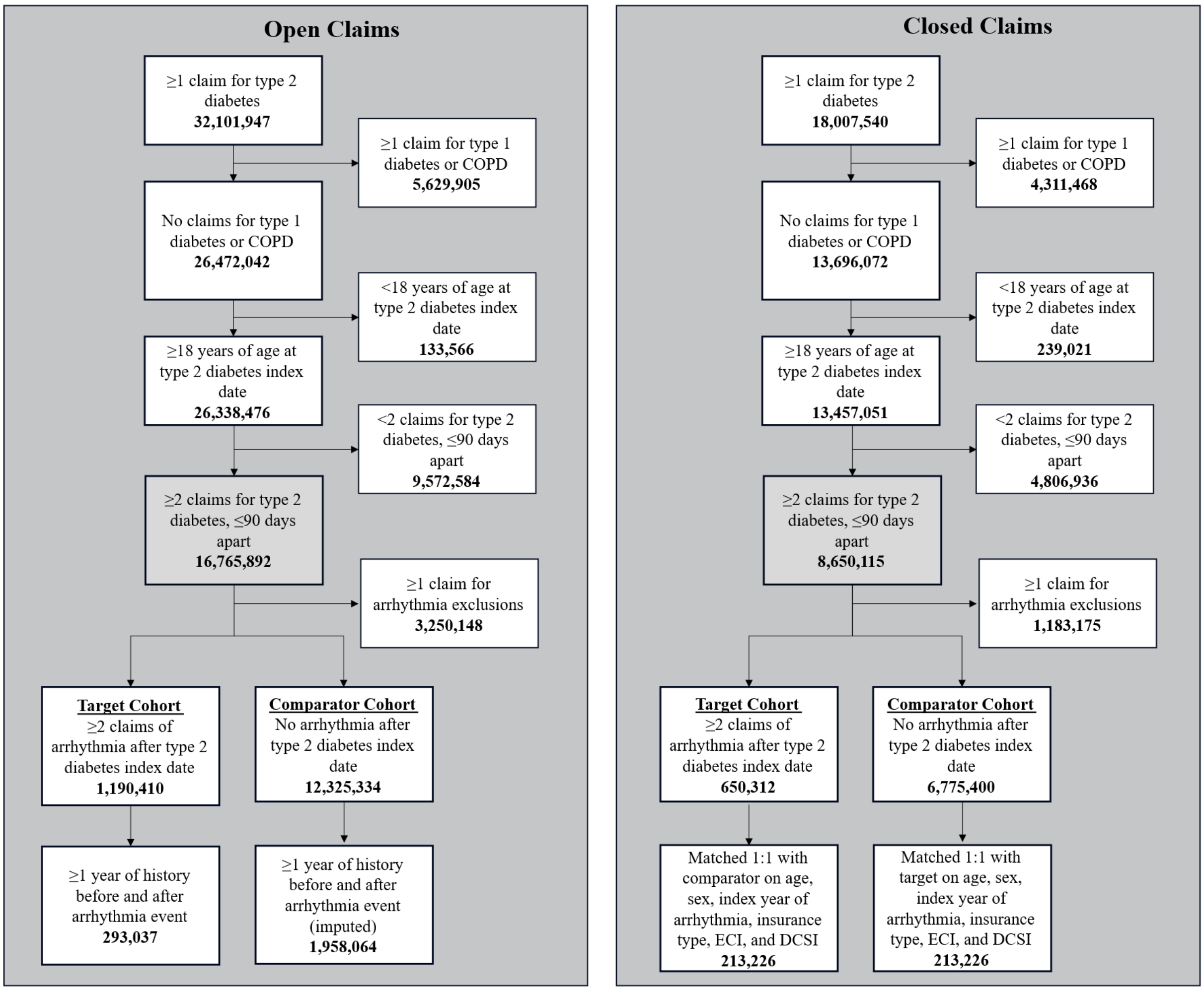

Figure 1 Patient identification in claims datasets.

18 years and older, during 2006-2023, with incidence arrhythmia diagnosis post-T2D, and following the same inclusion criteria as our first objective. We performed exact 1:1 matching of patients with arrhythmia to controls without arrhythmia on age, sex, geographic region, insurance type, Elixhauser Comorbidity Index (ECI) [14,15] and Diabetes Complication Severity Index (DCSI) [16,17].

ECI scores were stratified into five categories from negligible to severe, and DCSI scores were stratified into six categories (0,1,2,3,4,>5) based on the number of unique diabetes related complications that were observed in the 12 months leading to the initial diagnosis of arrhythmia. Comparator index dates were aligned to mirror the interval between T2D diagnosis and arrhythmia onset observed in the target group. HCRU outcomes included all-cause hospital admissions, Emergency Department (ED) visits, 30-day hospital readmissions, and total inpatient days. The statistical significance of the incremental differences in HCRU between matched cohorts were evaluated using generalized linear models with a negative binomial distribution and log-link function to manage skewness in data. Cost analyses were comprehensively captured across inpatient, outpatient, pharmacy, procedural, and diagnostic domains. Annual Per-Patient-Per-Year (PPPY) total costs and hospitalization costs were calculated, and the incremental differences between matched cohorts were evaluated using generalized linear models with a Tweedie distribution and log-link function to manage skewness in data.

Evaluating the impact of early detection *via* ambulatory cardiac monitoring

To evaluate the impact of ambulatory ECG monitoring among T2D with arrhythmia, we used the Symphony open claims dataset and identified incidence arrhythmia patients who received ambulatory cardiac monitoring at the time of arrhythmia detection, specifically Zio monitors (confirmed *via* CPT codes and specific NPI provider identifiers). To minimize heterogeneity, patients monitored with other types of cardiac devices were excluded. We then constructed two sub-cohorts of patients diagnosed with arrhythmia: T2D patients with incident arrhythmias, who were monitored *vs.* never monitored, matched exactly 1:1 on age, sex, region, insurance, ECI and DCSI. HCRU outcomes including hospitalization rates, ED visits, and 30-day readmissions, were compared between sub-cohorts within a 60-day window centered on the arrhythmia index date (30 days before and after). Utilization rates were expressed per 1,000 patients per month. Generalized linear models with negative binomial distribution was used to determine the statistical significance of the difference in HCRU between the two sub-cohorts.

Result

Study populations and predictors of arrhythmia

From a pool of 32 million T2D patients in the open claims data, 1.19 million adults (aged 18–80 years; 57% male, 43% female, median age: 71 years) developed arrhythmias with a median onset time of 18 months post-T2D diagnosis. The comparator cohort comprised of 12.3 million patients (48% male, 52% female, median age: 62 years) who did not develop arrhythmias (Table 1). The arrhythmia cohort exhibited a higher comorbidity burden, with 61% having an ECI above 5, compared to 12% in the non-arrhythmia group. Similarly, 28% of arrhythmia patients had a DCSI score of 2 or higher, *vs.* 10% in the non-arrhythmia group. SDOH disparities were not notable. Arrhythmia patients faced similar food insecurity (48% *vs.* 47%), financial strain (41% *vs.* 36%), and housing instability (4% *vs.* 4%). Transportation barriers affected 15% of arrhythmia patients and 21% in the non-arrhythmia cohort. While the p-values indicate significance, Cramer's V statistic shows that there are no meaningful associations between any of these SDOH variables. The clinical trajectory for arrhythmia patients included more diagnostic testing, increased cardiology visits, and higher prescription rates for beta-blockers, antiarrhythmics, and anticoagulants. Predictive modeling identified age over 65, hypertension, elevated DCSI, and food insecurity as the strongest predictors of arrhythmia onset.

Healthcare resource utilization and costs among matched cohorts

In the closed claims data, 213,226 (aged 18-80; 53% male, 47% female, median age: 62 years) of the 18 million patients with T2D were identified with arrhythmia and matched 1:1 with a comparator cohort of non-arrhythmia T2D patients. Healthcare

Table 1. Demographics and social determinants of health.

Demographics	Arrhythmia (N=1,190,410)	Non-Arrhythmia (N=12,325,334)		
Age Range, years, No. (%)				
18-34	5952 (0.5)	369760 (3)		
35-44	23808 (2)	986027 (8)		
45-54	71425 (6)	2095307 (17)		
55-64	202370 (17)	3327840 (27)		
65-70	214274 (18)	2218560 (18)		
71-75	214274 (18)	1479040 (12)		
76-80	416644 (35)	1602293 (13)		
>80	47616 (4)	246507 (2)		
Sex, No. (%)				
Female	511876 (43)	6409174 (52)		
Male	678534 (57)	5916160 (48)		
Insurance, No. (%)				
Commercial	583301 (49)	8011467 (65)		
Government	11904 (1)	123253 (1)		
Medicaid	59521 (5)	862773 (7)		
Medicare	523780 (44)	3204587 (26)		
Unknown	11904 (1)	123253 (1)		
Region, No. (%)				
North Central	261890 (22)	2341813 (19)		
Northeast	226178 (19)	2465067 (20)		
South	499972 (42)	5176640 (42)		
West	190466 (16)	2095307 (17)		
Unknown	11904 (1)	246507 (2)		
ECI, No. (%)				
Negligible (<2)	35712 (3)	9244001 (75)		
Low (2-5)	428548 (36)	1602293 (13)		
Moderate (6-10)	238082 (20)	739520 (6)		
High (11-15)	214274 (18)	493013 (4)		
Severe (>15)	273794 (23)	246507 (2)		
Number of DCSI Complications, No. (%)				
0	559493 (47)	8627734 (70)		
1	297603 (25)	2465067 (20)		

2	166657 (14)	862773 (7)		
3	95233 (8)	246507 (2)		
4	47616 (4)	123253 (1)		
5 or more	23808 (2)	0 (0)		
SDOH Variable	**Arrhythmia (N=412,354)**	**Non-Arrhythmia (N=3,928,184)**	**p-value**	**Cramer's V**
Highest Education Level, No. (%)			<0.001	0.027
Some High School	0 (0)	1 (<1)		
Completed High School	127830 (31)	1178455 (30)		
Attended Vocational/Technical	4124 (1)	39282 (1)		
Some College	49482 (12)	471382 (12)		
Completed College	82471 (20)	864200 (22)		
Completed Graduate School	107212 (26)	903482 (23)		
Unknown	41235 (10)	471382 (12)		
Mobile Home, No. (%)			0.01	<0.001
Yes	16494 (4)	157127 (4)		
Dwelling Type, No. (%)			<0.001	0.004
Single	366995 (89)	3496084 (89)		
Multi	41235 (10)	392818 (10)		
Unknown	4124 (1)	39282 (1)		
Family and Community Support, No. (%)			<0.001	0.005
Yes	342254 (83)	3221111 (82)		
Financial Strain, No. (%)				
Yes	169065 (41)	1414146 (36)	<0.001	0.028
Food Insecurity, No. (%)				
Yes	197930 (48)	1846246 (47)	<0.001	0.005
Transportation Problem, No. (%)				
Yes	61853 (15)	824919 (21)	<0.001	0.042

Table 2. Healthcare utilization and costs for type 2 diabetes patients that had arrhythmia and non-arrhythmia.

	Arrhythmia	Non-Arrhythmia	Effect Size (Risk Ratio)	95% Confidence Interval	P Value
Hospitalizations/ 1000 patients/year	395	139	2.85	2.82, 2.88	<0.001
Readmissions/ 1000 patients/year	95	51	1.86	1.80, 1.93	<0.001
ER Visit Days/ 1000 patients/year	985	468	2.1	2.09, 2.12	<0.001
Total Cost of Care, PPPY	$ 34171	$ 18687	1.83	1.81, 1.85	<0.001
Hospitalization Cost, PPPY	$ 28316	$ 19439	1.46	1.43, 1.49	<0.001

Table 3 Place of service for type 2 diabetes patients that developed an arrhythmia and non-arrhythmia.

Place of Service	Arrhythmia	Non-Arrhythmia	Effect Size (Risk Ratio)	95% Confidence Interval	P Value
Inpatient Hospital, PPPY	$ 24908	$ 15611	1.60	1.56, 1.63	<0.001
Outpatient Hospital, PPPY	$ 7760	$ 5152	1.51	1.48, 1.54	<0.001

Table 4 Healthcare utilization for Type 2 diabetes patients with arrhythmia detected by zio monitor and no-monitor.

	Arrhythmia Detected With Zio Monitor	Arrhythmia without Monitoring	Effect Size (Risk Ratio)	95% Confidence Interval	P Value
Hospitalizations/ 1000 patients/month	64	215	0.30	0.27, 0.33	<0.001
Readmissions/ 1000 patients/month	31	56	0.56	0.40, 0.79	0.001
ER Visit Days/ 1000 patients/month	103	202	0.51	0.47, 0.55	<0.001

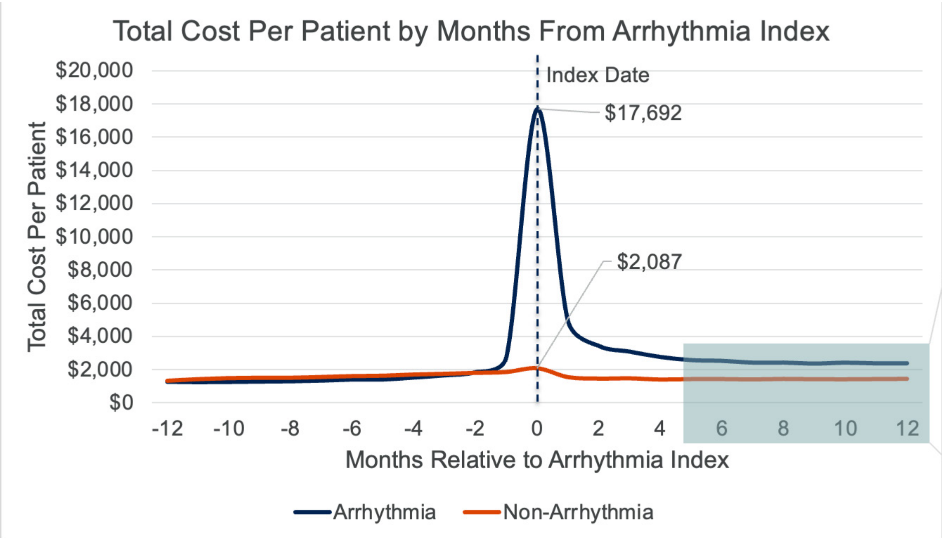

Figure 2 Cost of care per month before and after arrhythmia.

utilization was substantially higher among patients with arrhythmia (Table 2). Hospital admissions reached 395 per 1,000 patients per year for arrhythmia patients, compared to 139 in the non-arrhythmia group. Emergency department visits were 985 *vs.* 468 per 1,000 patients per year. Fourteen percent of the patients with arrhythmia were readmitted within 30 days of the previous discharge, compared to 9% of the patients without arrhythmia. The economic burden was also significantly greater.

Total annual per-patient healthcare costs were $34,171 for patients with arrhythmias, compared to $18,687 for the non-arrhythmia cohort. Annual per-patient hospitalization costs were $28,316 for the arrhythmia group *vs.* $19,439 for the non-arrhythmia group when normalized over hospitalized patients only. This disparity in total costs per-patient is concentrated around the time of arrhythmia diagnosis (Figure 2). When comparing the costs of care by place of service over the 24-month period surrounding the index date (Table 3), the arrhythmia cohort incurred significantly higher costs compared to the non-arrhythmia cohort among utilizing patients across inpatient hospitals ($24,908 *vs.* $15,611) and outpatient hospitals ($7,660 *vs.* $5,152) [18-24].

In the secondary study of patients monitored with the Zio cardiac arrhythmia monitor, 18% of patients were diagnosed with arrhythmias within 4 weeks of being monitored. The HCRU in patients with arrhythmia but never monitored with any cardiac arrhythmia monitor was significantly higher than in patients who were monitored with the Zio monitor, with over three times increase in all-cause hospitalization rate (215 *vs.* 64), almost two time increase in 30-day readmission rate (56 *vs.* 31) and in ER visits (202 *vs.* 103), all measured as per 1000 cohort patients per month (Table 4).

Conclusion

This study provides a comprehensive analysis of the relationship between T2D and cardiac arrhythmias, with a particular focus on the clinical and economic consequences of arrhythmias first identified in acute care settings. Our findings confirm that T2D is associated with a significantly higher burden of arrhythmias, compared to non-diabetic populations. This reinforces prior evidence that diabetes is an independent risk factor for arrhythmogenesis, driven by diabetes-specific pathophysiological mechanisms rather than just comorbid cardiovascular disease 18-22.

It has been already reported that T2D increases the risk of AF by approximately 40%. This elevated risk stems from a combination of structural changes such as atrial fibrosis, electrical remodeling including QTc prolongation and repolarization dispersion, and autonomic dysfunction. Notably, autonomic imbalance, especially in patients with diabetic autonomic neuropathy, has been identified as a key contributor. These patients often exhibit disrupted circadian variation in heart rate and QTc intervals, heightening the risk of arrhythmia during vulnerable periods, such as at night or early morning.

Additionally, reduced Heart Rate Variability (HRV), a validated marker of autonomic dysfunction, progressively declines along the diabetes continuum and correlates with greater arrhythmia risk. Hypoglycemia has also been shown to be arrhythmogenic. Acute episodes can trigger arrhythmias *via* a biphasic autonomic response, an initial sympathetic stimulation followed by parasympathetic rebound. This is particularly dangerous in individuals with cardiovascular disease or impaired autonomic regulation, underscoring the importance of continuous ECG monitoring in these high-risk groups.

A significant portion of clinical and economic burden in patients with T2D who develop major arrhythmias stems from undiagnosed arrhythmias, particularly silent AF, which can lead to serious complications like stroke or heart failure before detection. Approximately 11% of AF cases are estimated to go undiagnosed, with some populations showing rates as high as 23% over a two-year period. These findings highlight a major gap in early detection, which is critical for both clinical outcomes and cost containment. Ambulatory ECG monitoring offers a promising solution for early identification and risk stratification. In our analysis, T2D patients screened with wearable monitors showed a significantly lower rate of hospitalizations, 64 per 1,000 patients per month, compared to 215 per 1000 patients per month in the matched control group without monitoring. Emergency department visits were also up to 50% lower annually among the monitored group, supporting the clinical and economic value of early detection strategies.

Our analysis also suggests that unmet social needs are prevalent in T2D patients with arrhythmias, adding another layer of complexity to care. These findings support the integration of social risk screening and support services into comprehensive disease management models. Based on this evidence, two key implications emerge for potential interventions. T2D patients, especially those with poor glycemic control or signs of autonomic dysfunction, should be considered for extended ambulatory ECG monitoring. Combining wearable ECG monitoring with Continuous Glucose Monitoring (CGM) may allow for real-time risk identification and intervention.

This study also had limitations. This real-world evidence analysis, while highly generalizable, is observational in nature and subject to residual confounding. Lack of consistent, high-resolution ECG and glycemic data across all patients limited the ability to perform more granular risk stratification. Future studies should focus on longitudinal tracking of both arrhythmia burden and glucose dynamics.

In conclusion, T2D is a significant yet often underappreciated contributor to arrhythmia risk. Clinical management must go beyond glucose control to include early detection strategies with extended continuous ECG monitoring, and simultaneous CGM to improve targeted personalized interventions. These findings underscore the need for an integrated, value-based approach to diabetes care, one that addresses both medical and social risk factors to improve outcomes and reduce costs.

Conflicts of Interest Disclosure

BW, KB, and EH are employees of iRhythm Technologies and hold equity in the company. No other potential conflicts of interest relevant to this article were reported.

Author Contributions

PR, RN, BW, KB, and EH contributed to conception and design of the study. PR, RN, JP, and DP were involved in the data acquisition, analysis and interpretation. PR drafted the manuscript. All authors critically reviewed the manuscript for important intellectual content and approved the final version. PR, RN, JP, and DP conducted the statistical analysis. BW, KB, and EH obtained funding and provided administrative, technical, or material support. PR supervised the project and is the guarantor of the work, having full access to all the data and responsibility for the integrity of the data and accuracy of the analysis.

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Role of Funder/Sponsor: iRhythm Technologies, as the study sponsor, had no role in the conduct of the study; collection, management, analysis, or interpretation of the data; preparation of the manuscript; and decision to submit the manuscript for publication. Certain authors (BW, BK, and EH), as employees of iRhythm Technologies, were involved in the study's conception and design, critical review of the manuscript, and approved the final version as detailed in the Author Contributions section.

Key points

- Type 2 diabetics that developed arrhythmias experienced higher rates of comorbid conditions compared to those who did not develop arrhythmias.
- Type 2 diabetics that developed arrhythmias experienced higher healthcare resource utilization compared to matched controls that did not develop arrhythmias.
- Type 2 diabetics that developed arrhythmias experienced higher healthcare expenditures compared to matched controls that did not develop arrhythmias.

Question: What are the differences in healthcare resources utilization and costs associated with arrhythmias and ambulatory cardiac monitoring among type 2 diabetics?

Findings: In this retrospective, multi-source, claims-based cohort study of 32 million patients with type 2 diabetics, those who developed arrhythmias had a significantly higher comorbidity burden, healthcare resource utilization, and costs compared to those without arrhythmia. Patients who underwent ambulatory ECG monitoring had lower healthcare utilization and costs than those never monitored.

Meaning: Arrhythmias among type 2 diabetics are associated with substantial healthcare burden and costs, proactive detection through ambulatory cardiac monitoring may help mitigate this burden.

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