Journal of Multidisciplinary Healthcare

Dovepress
Taylor & Francis Group

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ORIGINAL RESEARCH

Type 2 Diabetes-Related Complications Among Commercial Pilots: Aeromedical Considerations from a Retrospective Cohort

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Purpose: Type 2 diabetes mellitus (T2DM) and diabetes-related complications can pose serious challenges to pilots by affecting their flight performance and professional careers. This study aims to investigate the emergence of complications in commercial pilots with T2DM through a retrospective evaluation of their aeromedical examination records.

Patients and Methods: The retrospective cohort study included 59 commercial pilots who had a confirmed diagnosis of T2DM in year 2012, whereas pilots without such diagnosis within that year were excluded from the study. Their examination records involving the first diagnosis of T2DM prior to 2012 and all subsequent records from 2013 to 2021 were comprehensively analyzed. Data included demographic information, smoking status, age of diabetes and complication onset, certain biochemical markers, complications, and aeromedical certification processes. Estimated glomerular filtration rate (eGFR) values were calculated in each record using the CKD- EPI equation, with chronic kidney disease determined as two consecutive eGFR measurements being <60 mL/min/1.73 m^2. Examination intervals varied from 6 to 12 months based on aeromedical regulations. Statistical analyses were performed using proper comparative tests, and multivariate logistic regression was employed to identify factors linked to complications.

Results: Of the 59 pilots, 28 (47.5%) had at least one complication, such as coronary artery disease (CAD), retinopathy, stroke, or diabetic kidney disease (DKD), with 14 of them diagnosed retrospectively by eGFR measurements. The prevalence of smoking was 30.5%, with 77.78% of them developing complications, indicating a significant relationship (p=0.004). The mean age at the diagnosis of T2DM was 50.16±6.62, while complications occurred at 58.64±5.69 years. No significant difference was found in the age of T2DM onset between pilots with complications and those without.

Conclusion: This study identified a strong association between smoking and diabetes-related complications, demonstrated a high rate of complications —primarily CAD and DKD— in pilots with T2DM, and underscored the importance of periodical examinations in detecting subclinical conditions. Routine eGFR measurement was also shown to be essential for the early detection of DKD diagnosis.

Keywords: diabetes mellitus, commercial pilots, complication of diabetes, aeromedical examination, flight safety, early diagnosis, diabetic kidney disease

Introduction

Diabetes Mellitus (DM) is a highly prevalent global disease with significant morbidity and mortality rates. Diabetes was reported to affect 11.1% of individuals aged 20 to 79 years worldwide, and was shown to account for 12% of global health expenditures.[1] Diabetes also remains a significant public health concern in Turkey. According to a comprehensive analysis of individuals with diabetes in Turkey by the end of 2020, the prevalence of diabetes was determined to be 11.12%.[2] Turkey was reported to have a diabetes prevalence of 16.5% among individuals aged 20–79 years in 2024, with an estimated 14.1 million people predicted to develop diabetes by 2050, ranking tenth globally.[1]

https://doi.org/10.2147/JMDH.S572696
Received: 8 October 2025
Accepted: 23 December 2025
Published: 9 January 2026

Diabetes causes serious long-term complications —involving coronary artery disease (CAD), retinopathy, nephropathy, etc.— as well as some acute problems such as hyperosmolar hyperglycemic state, acute hypoglycemia.[1] T2DM and its complications also have various adverse effects on pilots' flying skills and professional careers, resulting in flight license limitations and even termination.[3,4] Pilots are reported to have lower incidences of certain diseases such as CAD, asthma, T2DM (Type 2 Diabetes Mellitus), stroke, etc. compared to the general population.[5] However, such diseases and their complications may have the potential to cause serious consequences when they lead to medical incapacitation during the flight. Even though technological advancements have rendered air transportation indispensable, the extraordinary flight conditions require that the human factor —especially pilot health— remains to be a critical component of aviation safety management, demanding strict compliance with regulatory medical standards. Therefore, they undergo periodic aeromedical examinations (AEs), which should be comprehensive to detect any underlying medical conditions.[6]

Flight environment represent additional difficulties for those with diabetes, including limited accessibility to medical assistance, inadequate nutritional alternatives, and irregular intervals for routine treatment dosages.[7] The detrimental impacts of T2DM and its rising prevalence necessitate a thorough examination and proper monitoring of blood glucose levels (BGLs) among commercial pilots (CPs). Today, aeromedical fitness for T2DM may be considered with certain license limitations if strict and regular follow-ups with additional medical evaluations are maintained, while insulin is deemed unacceptable for commercial pilots.[8,9] Recent studies on diabetes within the aviation industry has increasingly concentrated on insulin treatment and pilot fitness for flight, and the aeromedical limitations for civilian pilots with insulin-dependent diabetes have recently been reassessed in various nations, resulting in less restrictive decisions as to being eligible for flight certification.[10,11] It has also been identified that insulin usage is advised in particular instances of T2DM, and the need for insulin is likely to rise as rates of T2DM increases.[12] Therefore, close monitoring of pilots with T2DM and DRCs is crucial in order to minimize further adverse consequences of the disease. Limited research was undertaken recently on the presence of T2DM among CPs globally, with a notable absence of studies investigating the progression of T2DM and DRCs among CPs. This study particularly aimed investigate the emergence of DRCs among CPs with T2DM by analyzing their AE records, and to evaluate their effects on aeromedical assessment procedures and flight safety.

Materials and Methods

Data Collection and Study Design

This study presents the first detailed analysis of CPs previously diagnosed with T2DM in Turkey. Ethical approval was obtained from Eskisehir Osmangazi University Committee of Clinical Research Ethics with decision number 80558721/ 209.

The study group consisted of 59 commercial pilots who had received a verified diagnosis of T2DM in the year 2012. On the other hand, pilots who did not have such a diagnosis in that year were excluded from the study. In 2012, all hardcopy records of previous AEs were digitally archived into the Directorate General of Civil Aviation (DGCA) database and following records have consistently been uploaded thereafter. An investigation was performed to evaluate the primary hardcopy records revealing the adequate information of the initial diagnosis for each CP with T2DM. Then a comprehensive assessment was undertaken on their digital AEs over a period of nine years, ranging from January 2013 to December 2021. Initiating the investigation at the onset of digital archiving in 2012 provided a long-term follow-up, enabling a complete and detailed evaluation of the disease progression and its management.

All accessed data complied with relevant data protection and privacy regulations, and no identifiable personal information was collected or utilized in the analysis. The dataset included CPs' demographical parameters, ages of diabetes and DRC onset, smoking status, biochemical markers, types of reported DRCs occurred during the nine-year period, and information (status of fitness-to-fly, limitations, etc.) about their aeromedical certificates. Besides, in order to investigate the presence and development of Chronic kidney disease (CKD) and Diabetic kidney disease (DKD), the estimated glomerular filtration rate (eGFR) values were calculated by utilizing serum creatinine results with Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) 2021 eGFR creatinine equation in each AE record. CKD was defined as an initial measurement of eGFR < 60 mL/min/1.73 m^2.[13] DKD was defined as a decrease in eGFR to below 60 mL/min/1.73 m^2 documented in at least two consecutive AEs in CPs who had an initial value of eGFR ≥60 mL/min/1.73 m^2. CPs are required to undergo periodic AEs annually according to aeromedical standards. This interval can be

modified if a health condition requires close follow-up, allowing the physician to determine the appropriate time for special conditions.[9,14] Hence, the time of two consecutive AEs —and, as a result, the periods between related eGFR measurements— ranged from six to twelve months.

The flight careers of all these pilots did not conclude because of any medical problem, since it was observed that they were all assessed as fit for flight —albeit with certain limitations— in their latest aeromedical records. Therefore, the evaluation ended in December 2021 as no further medical records have been identified in the database after that date.

Statistical Analyses

Statistical analysis was performed in SPSS 18.0 (SPSS Inc., Chicago, IL, USA). Data were expressed as median and interquartile range (25th-75th) or mean and standard deviation for continuous variables or as number of cases and percentages (%) for categorical variables. The Mann–Whitney *U*-test was used to compare differences between two groups. Categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate.

Binary logistic regression was performed to ascertain the association between different variables and the presence of diabetes complications. Variables with a p-value of less than 0.20 in the univariate analysis, as well as those that did not create multicollinearity, were entered into the multivariate model. Hosmer-Lemeshow goodness of fit statistics were used to assess model fit. Variables were evaluated at a 95% confidence level, and a value of $p<0.05$ was considered statistically significant.

Results

There were 3678 active CPs by the end of 2012.[14] During that year, 59 CPs who had been previously diagnosed with T2DM were identified. Diabetes prevalence was found to be 1.6% among CPs. All 59 pilots were males.

The mean age of 59 pilots at the time of T2DM diagnosis was 50.16±6.62. The mean age at which DRCs developed was 58.64±5.69. The mean age of T2DM onset among pilots who developed DRCs was 49.82±6.07, while it was 50.77 ±6.81 among those who did not. However, no statistically significant difference was found between the mean ages of T2DM onset in terms of DRCs development.

18 of 59 T2DM pilots were found to have smoking history, with a prevalence of 30.5%. 14 of the smoker pilots (77.78%) had developed DRCs in the following years. A statistically significant difference was found in DRCs development between pilots with DRCs and those without (p=0.004). (Table 1).

Throughout the nine-year period, 17 (28.81%) of the 59 CPs developed 18 DRCs, each of which was formally documented in the AE records. Among these, 12 pilots were diagnosed with CAD, two had diabetic retinopathy (DR), one had both CAD and DR, one had ischemic stroke (IS), and one had DKD (Table 2). In addition to these 17 pilots, we

Table 1 Demographic Characteristics and Laboratory Values of Patients with and without Diabetes Complications

	DM Without Complications (n = 31; 52.54%)	DM with Complications (n = 28; 47.46%)	p-value
Age, *years*	65 (13)	63.5 (7)	NS
Smoking, %	4 (12.9%)	14 (50%)	0.004
CKD at diagnosis, %	8 (25.8%)	3 (10.7%)	NS
BMI, kg/m^2	27.7 (4.3)	27.3 (4.2)	NS
Diabetes age, *years*	12 (2)	13 (1)	NS
Age at diagnosis, *years*	51 (12)	51.5 (7)	NS
BMI at diagnosis, kg/m^2	28.1 (3.8)	27.3 (4.9)	NS
FPG at diagnosis, *mg/dl*	142 (42)	138 (34.8)	NS

(*Continued*)

https://doi.org/10.2147/JMDH.S572696

Table 1 (Continued).

	DM Without Complications (n = 31; 52.54%)	DM with Complications (n = 28; 47.46%)	p-value
HbA1c at diagnosis, %	6.9 (1.5)	6.7 (1.7)	NS
eGFR at diagnosis, *mL/min/1.73 m²*	66.5 (18.9)	72.1 (21.6)	NS
eGFR at last visit, *mL/min/1.73 m²*	67.6 (13.4)	58.5 (15.5)	0.002
LDL-C at diagnosis, *mg/dl*	115 (63)	126.2 (54)	NS
TG at diagnosis, *mg/dl*	188 (110)	154.5 (125.8)	NS
HDL-C at diagnosis, *mg/dl*	47 (13)	45.4 (18.4)	NS
TyG index at diagnosis	9.5 (0.6)	9.3 (0.9)	NS
Glucose-lowering therapy at diagnosis			
Metformin, %	31 (100%)	27 (96.4%)	NS
Alpha-glucosidase inhibitor, %	0 (0%)	1 (3.6%)	NS

Abbreviations: DM, diabetes mellitus; CKD, chronic kidney disease; BMI, body mass index; FPG, fasting plasma glucose; eGFR, estimated glomerular filtration rate; LDL-C, low density lipoprotein cholesterol; TG, triglyceride; HDL-C, high density lipoprotein cholesterol; TyG index, triglyceride-glucose index; NS, not significant.

Table 2 T2DM-Related Complications Formally Documented in the Aeromedical Records During the Nine-Year Period

Pilot	DRC	Presentation	Abnormalities Identified	Intervention	Aeromedical Decision with an OML After 6-Months Unfit Period
1	CAD DR	Detected during PE Detected during PE	Ischemic areas in MPS Bilateral NPDR	PTCA + stenting Observation for DR	Fit assessment with an OML after a 6-month unfit period
2	CAD	Detected during PE	Abnormal ECG findings Positive CST	PTCA + CABG	
3	CAD	Detected during PE	Abnormal ECG findings Positive CST	PTCA	
4	CAD	Detected during PE	Abnormal ECG findings Positive CST	PTCA + stenting	
5	CAD	Detected during PE	Abnormal ECG findings Positive CST	PTCA	
6	CAD	Detected during PE	Positive CST	PTCA + Stenting	
7	CAD	Detected during PE	Abnormal ECG findings Positive CST	PTCA + CABG	
8	CAD	Detected during PE	Positive CST	PTCA	
9	CAD	Detected during PE	Positive CST (in two consecutive examinations)	PTCA + stenting	
10	CAD	Detected during PE	Positive CST	PTCA	
11	CAD	Chest pain	Abnormal ECG findings Elevated cardiac markers	PTCA + stenting	
12	CAD	Chest pain	Abnormal ECG findings Elevated cardiac markers	PTCA + stenting	
13	CAD	Chest pain	Abnormal ECG findings Elevated cardiac markers	PTCA + stenting	

(*Continued*)

Table 2 (Continued).

Pilot	DRC	Presentation	Abnormalities Identified	Intervention	Aeromedical Decision with an OML After 6-Months Unfit Period
14	DR	Detected during PE	Bilateral NPDR	Observation	Fit assessment with a TML (follow-up at least every 6 months)
15	DR	Detected during PE	CSC in right eye	Intravitreal Anti-VEGF therapy	Fit assessment with a TML (follow-up at least every 3 months)
16	IS	Dysarthria and impaired writing in right hand	Occlusion of the right MCA at the M1 segment, 80% stenosis of the left M1 segment	Antiplatelet therapy with clopidogrel	Fit assessment with an OML after 6-months unfit period
17	DKD	Detected during PE	Increased creatinine levels, Decreased e-GFR level	Stage 3 chronic kidney disease	Fit assessment with an OML (follow-up at least every 3 months)

Abbreviations: CABG, coronary artery bypass grafting; CAD, coronary artery disease; CSC, central serous chorioretinopathy; CST, cardiac stress test; DKD, diabetic kidney disease; DR, diabetic retinopathy; DRC, diabetes-related complication; DSA, digital subtraction angiography; ECG, electrocardiogram; e-GFR, estimated glomerular filtration rate; IS, ischemic stroke; MCA, middle cerebral artery; MPS, myocardial perfusion scintigraphy; NPDR, nonproliferative diabetic retinopathy; OML, operational multipilot license; PE, periodic examination; PTCA, percutaneous transluminal coronary angioplasty; TML, time limitation; VEGF, vascular endothelial growth factor.

retrospectively detected CKD in 14 pilots whose disease had not been diagnosed and documented in their AE records. Three of these 14 CPs had also been documented as having DRCs, one with DR and two with CAD. Consequently, a total of 28 CPs had developed at least one DRC, either reported in their AEs or detected via retrospective eGFR calculation, suggesting an overall DRC incidence of 52.54%. Upon diagnosis, all our pilots were prescribed non-hypoglycemic oral antidiabetics (OADs), mostly metformin, with only one receiving an alpha-glucosidase inhibitor. The laboratory values and demographic characteristics of all pilots were presented in Table 1.

Comparative analysis of eGFR showed statistically significant differences among the CPs without DRCs, with DKD and with other DRCs (excluding DKD) ($p<0.001$). Pilots without DRCs demonstrated the highest eGFR values, while those with DKD exhibited significantly decreased renal function. Pilots having other DRCs (excluding DKD) showed average eGFR values. The results depicted in Figure 1 demonstrate the anticipated gradient of renal failure correlated with increasing DRC.

Multivariate logistic regression analysis indicated a significant positive association between smoking and the DRCs (OR 9.13, 95% CI: 2.06–40.35, p=0.004). This finding suggests that the risk of DRCs is more than nine times higher in smokers than in non-smokers. Among the other parameters evaluated, no statistically significant relationship with DRCs was found (Table 3).

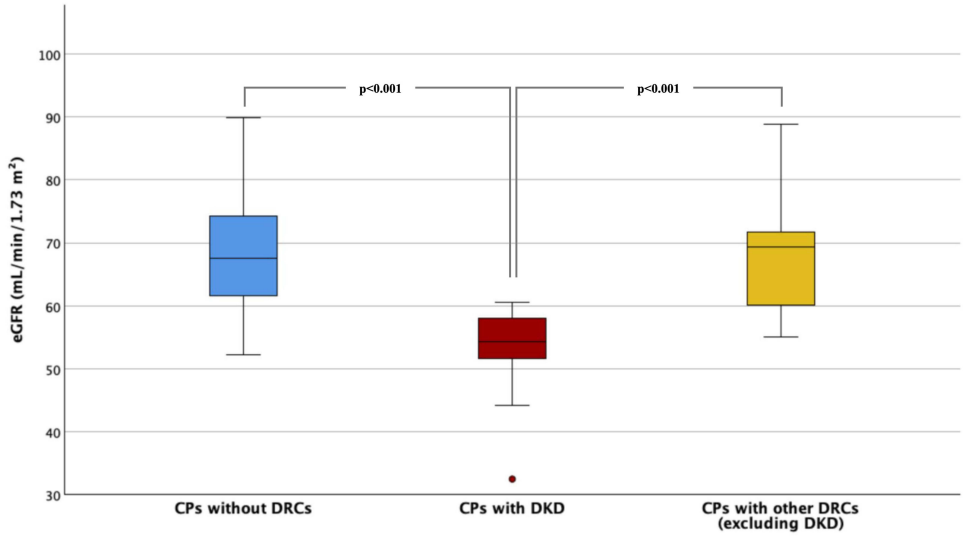

Figure 1 Comparison of eGFR levels among commercial pilots categorized as having no DRCs, those with DKD, and those with other DRCs (excluding DKD).
Abbreviations: eGFR, estimated glomerular filtration rate; CP, commercial pilot; DRC, diabetes-related complication; DKD, diabetic kidney disease.

https://doi.org/10.2147/JMDH.S572696

Table 3 Multivariate Logistic Regression Analysis for Estimating the Probability of Diabetes Complications

Variable	OR	95% CI	p-value
Age	0.64	0.26–1.59	NS
Smoking	9.13	2.06–40.35	0.004
CKD at diagnosis	0.22	0.04–1.31	NS
Diabetes age	2.22	0.82–6.04	NS
Age at diagnosis	1.57	0.63–3.93	NS
BMI at diagnosis	1.02	0.75–1.37	NS
BMI at last visit	0.95	0.71–1.27	NS
HbA1c at diagnosis	0.80	0.50–1.30	NS
TyG at diagnosis	2.24	0.56–8.90	NS

Note: $R^2 = 0.35$.
Abbreviations: OR, odds ratio; CI, confidence interval; CKD, chronic kidney disease; BMI, body mass index; TyG index, triglyceride-glucose index; NS, not significant.

Discussion

In this nine-year retrospective cohort of 59 CPs with T2DM, almost half (47.5%) developed at least one DRC. In multivariate analysis, smoking was the only positive associated predictor for DRCs, and smokers were approximately nine times more likely to develop DRCs than non-smokers. Complications included macrovascular diseases (most commonly CAD), and microvascular diseases (notably DKD and DR). DKD was found in 25.4% of CPs when eGFR was calculated retrospectively, although there was no mention of this complication in aeromedical examinations.

DM is a serious public health concern, and its incidence is predicted to increase, yet it is also critically important to occupational health and safety, requiring close monitoring and causing complications and disabilities.[15] DM has also been encountered in aviation industry as air transport developed globally. In Japan Airlines, 4.78% of CPs were reported to be under observation for T2DM or impaired glucose tolerance.[16] According to another study, the prevalence of DM in CPs increased from 0.31% in 1983 to 1.57% in 2005.[17] In our research, the prevalence of DM was found to be 1.6% among our CPs. Although this rate appears to be consistent with published literature, the goal of reducing diabetes incidence should always be the main priority of health policies in aviation industry.

Age plays a significant role in both the onset and management of T2DM. The frequency and severity of T2DM rise with advancing age, leading to various complications.[18] The employment and career effectiveness of individuals with diabetes pose significant concerns with ageing, not only for themselves and their families, but also for companies and legislators in terms of occupational persistence. Diabetes, particularly in individuals aged over 50, has been shown to result in significant burdens, such as earlier retirement, reduced effective labor time, and increased mortality rates in which CADs were the most common reason.[19] The mean age at which DRCs emerged in our pilots was determined to be over 50, with CADs being the most common cause. A study examining the reasons of medical disqualification among Turkish civil aviation pilots found that cardiovascular and circulatory system disorders were the main cause of permanent disqualification in individuals aged 50 and above.[4] In addition, an earlier onset of T2DM is linked to a higher probability of developing complications.[18] The mean age of T2DM onset in our pilots with DRCs was lower than that of those who did not. Current regulations require at least two CPs to be present in the cockpit, and the maximum mandatory age limit for multi-pilot CAT (commercial air transport) operations is 65 years.[20] Therefore, CPs with diabetes should always bear in mind that diabetes itself and DRCs may inevitably worsen their health and so result in unemployment and early retirement.

The initial and periodical AEs have been conducted in accordance with the regulations issued by the DGCA of Turkey and European Aviation Safety Agency (EASA).[8,9] At the time T2DM was diagnosed and appropriate medication was initiated, HbA1c and plasma protein levels were also measured, and a series of additional examinations were performed, including fundoscopic examination, detailed neurological examination, and certain cardiovascular examinations such as echocardiography and cardiac stress test, to maintain early detection of any DRC. Throughout the nine-year period, 17 pilots developed DRCs, with 13 CADs accounting for the majority. According to the Framingham Heart Study, patients with diabetes were shown to have a two to fivefold increased risk of cardiovascular disease.[21] It may also be said that such an increased risk inevitably rubs off on occupational persistence. In a recent study among CPs, atherosclerotic heart disease was found as the primary reason for permanent and ranked second for temporary disqualification for flight duties.[4] An EASA study revealed that the leading reason of disqualification among CPs was cardiovascular disorders, accounting for 19% of cases.[22] The incidence rate of CAD among 59 pilots was found to be 22.03%. CAD was detected in 13 (76.47%) of 17 pilots with DRCs. Besides, a CAD pilot underwent his second percutaneous transluminal coronary angioplasty (PTCA) six months after his first intervention because of a positive stress test encountered during his periodic AE. According to the guidelines, pilots with CAD were all deemed temporarily unfit for flight following the interventions (PTCA, stenting and coronary artery bypass grafting [CABG]) and grounded for six months. It should also be ensured that the pilot's cardiac functions pose no risk of incapacitation and are adequate to tolerate flight conditions before returning to flight duties.[8,9] Following satisfactory evaluations, those 13 CAD pilots all returned to flight with operational multipilot limitation (OML). A pilot holding an aeromedical certificate with an OML should fly together with the pilot who has a certificate without any limitations because if the pilot with OML becomes incapacitated during the flight, the other should be able to take control of the aircraft and continue the flight safely. Therefore, those pilots' licenses were revalidated with OML.

Although a commercial aircraft cruises at 31–38,000 feet altitudes, where conditions are extremely incompatible with human life, the cabin is artificially pressurized to around 8,000 feet to mitigate the risk of hypoxia, barotrauma, and decompression sickness and thus, to prevent passengers and aircrew from medical incapacitation.[23] The oxygen content of cabin air is approximately 15%, creating a mild hypoxic environment. Healthy individuals can tolerate this hypoxia, but those having any underlying disease that could increase their susceptibility to hypoxia cannot.[24] In our study, it was found that three pilots were diagnosed with CAD after presenting to emergency departments with chest pain, while ten were diagnosed during the further evaluations within the periodic AEs. Mild hypoxia inside the cabin can cause a tachycardia response, increasing myocardial oxygen demand. When someone has an underlying CAD with no symptoms at sea level, the increased oxygen demand at altitude may lead to cardiac decompensation.[25] Cardiovascular diseases were found to be one of the leading causes of in-flight incapacitations among CPs.[26] Besides, T2DM individuals may have silent myocardial ischemia due to autonomic neuropathy, which can mask any warning signs of an acute cardiac event.[27] Hence, CAD has a high risk of causing sudden medical incapacitation, rendering the pilot unable to perform flight missions properly.

Smoking was identified as the sole factor that was significantly correlated with DRC development. This significance, despite the small sample size, might be said to highlight its importance as an effective indicator of DRCs. In our study, DRC incidence among pilots who had smoking history was found significantly higher than that among non-smokers. Besides, out of the 13 CAD pilots, nine (69.23%) had a history of smoking, indicating a potentially considerable association with CAD. Smoking was shown to have significant effects on DRC development, including atherosclerosis and CAD, and has been identified as one of the primary independent risk factors for CAD in T2DM patients.[28] Smoking prevalence was also found to be 30.5% among our pilots. A systematic review, involving a collection of literature on smoking among T2DM individuals, reported a global mean prevalence of 20.81%.[29] A 14.2% prevalence of smoking was reported among T2DM individuals in a French population-based study.[30] Even though CPs have lower smoking rates than the general population,[31] smoking prevalence in our group was higher than the rates found in literature. An odds ratio above nine underscores the significant influence of smoking on the DRC development. The results align with the literature indicating that smoking increases micro- and macrovascular complications in patients with diabetes via causing endothelial dysfunction, oxidative stress, and inflammation[32,33] The AE records of CPs who had been smokers prior to receiving treatment for CAD were also analyzed, and it was observed that all had completely quit smoking following the

diagnosis of CAD. Therefore, besides making lifestyle changes such as regulating their dietary and physical activity routines, pilots should also give up smoking, particularly before any complications develop, to prevent the harmful effects of diabetes and DRCs.

DR was another pathology developed in three CPs, one having both CAD and DR. High BGLs were shown to trigger a variety of inflammatory reactions that eventually result in progressive vision loss.[34] In flight conditions, even minor impairments become more significant due to the retina's high sensitivity to hypoxia. Gradual deterioration of retinal pigments causes decreased color perception, which primarily affects vision during night flights.[35] Besides, degenerative and edematous changes in the macula due to diabetes may lead to impaired visual field[36] and reduced contrast sensitivity,[37] all of which can cause misjudgment of flight instruments and out-the-window visual cues, increasing the risk of in-flight incapacitation. These three pilots were all deemed temporarily unfit for flight duties and grounded for a limited period of time, depending on their clinical follow-up processes. Since their retinopathy status caused no visual field loss and had no effect on visual acuity, they were considered fit for flight and their licenses were revalidated with TML, a type of limitation that requires a detailed medical evaluation of the related pathology prior to the routine periodic assessment.

IS was another complication manifested in one of our pilots. He was diagnosed after presenting to the emergency department with dysarthria and impaired writing in his right hand. IS usually present with acute symptoms, as observed in our pilot, including sudden blurred or reduced vision, numbness, weakness or paralysis in the face, or any extremity, and even impairment in consciousness,[38] all of which may cause incapacitation if encountered during flight. Diabetes is not only a substantial risk factor for IS but also has adverse effects on post-stroke consequences.[39] Therefore, it is crucial to maintain normal BGLs and to perform additional evaluations properly. Once the stability and control had been achieved in the progression, the pilot was considered fit for flying with OML and was assigned detailed follow-up routines at frequent periods.

DKD may develop due to uncontrolled T2DM, leading to functional and structural damage to the kidney, yet it generally remains asymptomatic and might be identified in its initial stages through further evaluations.[40] The American Diabetes Association's "Standards of Care in Diabetes—2025" states that measuring the level of albuminuria via Albumin- Creatinine Ratio (ACR) in a spot urine and calculating eGFR provide an important benefit in evaluating DKD status among patients with diabetes.[41] It is important to point out that complete urine analyzes were routinely performed in our AEs; yet they did not involve testing ACR for detecting albuminuria. Therefore, in accordance with ADA 2025 guidelines, which classifies CKD risk depending on both albuminuria and eGFR, only the eGFR levels in our study could be retrospectively evaluated. A prolonged reduction of eGFR below 60 mL/min/1.73 m^2 has been shown to frequently result in the manifestation of CKD symptoms, which grow more serious as CKD worsens.[42] As aforementioned, the intervals between eGFR measurements ranged from six to twelve months. Consequently, the criteria of at least two consecutive eGFR measurements below 60 mL/min/1.73 m^2 and the persistent eGFR decline in our research may be said to reveal an increased risk and an alarming rate of DKD in this occupationally specialized population. Besides, it would be cautious to begin frequent monitoring at the time eGFR measurements fall below that threshold.

Regardless of decreased eGFR levels we detected in other CPs, our evaluation revealed that just one pilot had been diagnosed —and formally documented— as having DKD as a result of a reduction in eGFR to 42.11 mL/min/1.73 m^2 and rise in ACR to 258 mg/g. This poses questions regarding the possibility of inadequate awareness of DKD development in our CPs, which we retrospectively identified. A potential explanation for such diagnostic misstep may be the absence of standardized eGFR reporting in test results. ACR testing of DKD-diagnosed pilot must have been administered as an additional test, because while blood creatinine levels are regularly analyzed, the detection of albuminuria necessitates a particular request of ACR with a spot urine analysis, which is not regularly administered within our AEs. Hence, physicians may skip checking creatinine results and fail to recognize the deterioration of renal functions. It has been reported that regular presence of calculated eGFR values in laboratory reports increases physician recognition of CKD and raises the referrals to nephrology, thereby serving as an important preemptive action.[43,44] It is advised that individuals with CKD undergo monitoring of urinary albumin and eGFR on a regular basis, ranging from one to four times a year, depending upon the degree of the disease.[40] Frequent monitoring of ACR or eGFR and nephrology referrals in AEs are also recommended while assessing pilots living with diabetes.[45] Consequently, during

these AEs, the inclusion of automated eGFR measurement within routine laboratory test results together with creatinine levels could probably raise clinicians' recognition of potential decrease in renal functions, and thus, enable earlier identification and management of DKD. In order to accurately identify potential insidious impairment in renal functions, besides blood glucose management, additional and frequent assessments that incorporates both eGFR and ACR would be more useful.

Just as in the aviation industry, it is critical to conduct routine examinations in all occupational fields, together with additional assessments, in order to identify latent or emergent conditions prior to their manifestation. It has been demonstrated that regular medical checks in a variety of occupational disciplines might improve employees' health consciousness while preventing work-related diseases and incidents.[46,47] At first glance, additional tests and examinations may appear to impose a financial and psychological burden on health expenses and career maintenance of CPs. However, these burdens might be considered negligible when it comes to minimizing the incapacitation risk and hence preserving flight safety. 14 of our 18 documented DRC cases had been detected during periodical examinations, while four of them presented with urgency symptoms. Periodical AEs seem to prove their success, with over 70% of DRCs detected during regular examinations. Therefore, both routine AEs and additional evaluations may be said to have worked in determining subclinical —and maybe imminent— pathologies and prevented a probable incapacitation event before catastrophic consequences occurred. Our findings also emphasize the importance of developing aeromedical standards that specifically integrate standardized monitoring procedures for T2DM and its related complications, including regular assessments of both renal and metabolic risk factors. Such strategies could facilitate more accurate, evidence-based evaluations of fitness for flight and could be beneficial in decreasing preventable complications among active pilots.

Diabetes also has acute effects due to glycemic alterations. High BGLs were shown to cause significant impairment in cognitive functions.[48] Hypoglycemia, on the contrary, causes more negative and severe symptoms, ranging from impairments in verbal working memory and language functioning to blurred or limited vision, mental confusion, and unconsciousness.[49] In aviation, hypoglycemia was shown to impair the pilots' ability to execute the required tasks properly.[50] Besides, in-flight hypoglycemia accompanied by loss of consciousness could be extremely hazardous.[3] Hypoglycemia, particularly in T2DM, was revealed to increase the risk of cardiac arrhythmias,[51] potentially leading to incapacitation and subsequent loss of unconsciousness. OADs play an important role in regulating BGLs in T2DM; however, some medications are incompatible with flight duties due to various side effects, especially hypoglycemia. According to the regulations, insulins, sulphonylureas and glinides are considered unacceptable for CPs due to their significant potentials to induce hypoglycemia.[9] Although various OADs like metformin, thiazolidinediones, dipeptidyl peptidase IV inhibitors, etc. are both antihyperglycemic and non-hypoglycemic agents and are unlikely to cause significant hypoglycemia,[52] they can only be used with OML during flight operations.[9] Upon diagnosis, all our pilots were prescribed non-hypoglycemic OADs, mostly metformin, and issued fit for flight with OML.[53]

This study has certain limitations. First, the absence of ACR evaluation. AE protocols did not include regular ACR testing in periodic assessments. In addition, the results of routine laboratory tests did not include automated eGFR measurements together with creatinine levels. The diagnosis of DKD in the formally documented case was issued by the assessment of the additional ACR testing in conjunction with eGFR measurement, probably after the awareness of highly elevated creatinine levels. Besides, although the data we have collected extends only up to 2021, no changes have been made to Türkiye's aeromedical assessment requirements since then, and current AEs—involving the absence of periodic ACR evaluations—are still in accordance with the regulations that were implemented during our study period. Another limitation is the relatively small sample size, that could be attributed to the specific occupational population — commercial pilots. This group of individuals is required to meet detailed and rigid aeromedical assessment criteria upon admission and remains under regular health monitoring through periodical aeromedical assessments to maintain optimal health condition. Therefore, this cohort may be said to encounter a lower incidence of chronic diseases and related complications compared to general population. Furthermore, given its retrospective design, the study might be affected by potential biases, including incomplete or inadequately documented historical information; nonetheless, all accessible records were thoroughly evaluated to minimize such limitation.

Conclusion

This present research reveals novel viewpoints into the emergence of DRCs among CPs with T2DM, by retrospectively assessing AE records throughout a nine-year period. The most frequent diagnoses were CAD and DKD, with over half of the study cohort developing DRC. Our findings also emphasize the importance of implementing standard eGFR reporting to enhance the early recognition of subclinical DKD. In addition, smoking was identified as an associated factor in increasing DRCs, despite the small cohort size. It is also noteworthy that the documented DRCs had been actually identified during periodic AEs. This might be considered as a preventative measure, enabling the detection of preclinical or imminent conditions and preventing potential incapacitation events prior to the occurance of adverse consequences. Furthermore, multicenter and large-scale studies need to be performed to confirm such results and improve the scientific basis for the AEs of pilots with T2DM.

Ethical Approval

Ethical approval was obtained from Eskisehir Osmangazi University Committee of Clinical Research Ethics with decision number 80558721/ 209.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors have no conflicts of interest in this work.

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