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Araştırma Makalesi

Diagnostic performance of urinary biomarkers and self-monitoring blood glucose in estimating microvascular complications in elderly patients with diabetes mellitus

Yaşlı diyabetli hastalarda mikrovasküler komplikasyonları tahmin etmede idrar biyobelirteçlerinin ve kendi kendine kan glikozu izlemenin tanısal performansı

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Abstract

Aim: In elderly patients, detection of diabetes mellitus (DM)-associated complications is crucial to improve quality of life and prevent serious pathologies. This study aimed to evaluate the diagnostic performance of urine microalbumin-creatinine ratio (uMCR), urine protein-creatinine ratio (uPCR), and self-monitoring blood glucose (SMBG) in estimating microvascular complications, neuropathy, retinopathy, and nephropathy in older adults with DM.

Material and Methods: In this diagnostic methodological study, DM patients (n=99) older than 64 years were followed in the endocrinology clinic parameters; serum hemoglobin A1c (HbA1c), serum triglyceride-glucose index (TyG index), the difference between self-measured peak glucose level and nadir level (SMBGdiff), and the ratio of the SMBGdiff to the highest SMBG level (SMNGratio), uMCR and uPCR were evaluated by ROC analysis and their cut-off values and specificity were determined to evaluate the diagnostic power for microvascular complications.

Results: Our findings showed that 70% of the patients were male, 48.5% had neuropathy, 25.3% had retinopathy and 25.3% had nephropathy. Although lipid metabolism and liver-related indicators were within the normal range, patients were vitamin D deficient. ROC analysis revealed that uMCR and uPCR levels were independently associated with nephropathy ($p<0.001$), with strong specificity and moderate sensitivity. SMBGdiff was associated with both retinopathy and neuropathy ($p=0.049$ and $p=0.040$), and both specificity and sensitivity were poor.

Conclusion: In elderly patients with DM uMCR and uPCR are strong indicators of nephropathy. However, other diabetes-associated biomarkers showed poor correlations emphasizing the age-related complexities in diabetic patients and an urgent need for further research.

Keywords: Type 2 diabetes, retinopathy, neuropathy, nephropathy, urine microalbumin-creatinine ratio, protein-creatinine ratio

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Öz

Amaç: Yaşlı hastalarda yaşam kalitesini artırmak ve ciddi patolojileri önlemek için diabetes mellitus (DM) ile ilişkili komplikasyonların saptanması çok önemlidir. Bu çalışmanın amacı, DM'li yaşlı erişkinlerde üriner mikroalbümin-kreatinin oranı (uMCR), üriner protein-kreatinin oranı (uPCR) ve kendi kendine kan şekeri takibinin (SMBG) nöropati, retinopati ve nefropatiyi gibi mikrovasküler komplikasyonları tahmin etmedeki tanısal performansını değerlendirmektir.

Gereç ve Yöntemler: Bu tanısal metodolojik çalışmada, endokrinoloji kliniğinde takip edilen 64 yaş üstü DM hastalarının (n=99) serum hemoglobin A1c (HbA1c), serum trigliserid-glukoz indeksi (TyG indeksi), SMBG ile ölçülen en yüksek ve en düşük kan şekeri düzeyleri farkı (SMBGfarkı) ve SMBGfarkı ile en yüksek SMBG düzeyinin oranı (SMBGoranı), uMCR ve uPCR değerleri, mikrovasküler komplikasyonları tahmin etmedeki tanısal güçleri ROC analiziyle değerlendirildi. Tanısal performansa sahip olanların kesim değerleri ve sensitivite ve spesifiteleri hesaplanmıştır.

Bulgular: DM hastalarının %70'inin erkek olduğunu, %48,5'inde nöropati, %25,3'ünde retinopati ve %25,3'ünde nefropati olduğunu göstermiştir. Lipid metabolizması ve karaciğerle ilgili göstergeler normal aralıkta olmasına rağmen, hastalarda D vitamini eksikliği görülmüştür. ROC analizi, uMCR ve uPCR düzeylerinin bağımsız olarak nefropati ile ilişkili olduğunu ($p<0.001$), güçlü spesifisite ve orta düzeyde duyarlılık gösterdiğini ortaya koymuştur. SMBGfarkı hem retinopati hem de nöropati açısından istatistiksel olarak anlamlı tanısal performansa sahip ($p=0.049$, $p=0.040$), ancak hem spesifite hem de sensitivite düzeyleri düşüktür.

Sonuçlar: DM'lu yaşlı hastalarda uMCR ve uPCR nefropatinin güçlü göstergeleridir. Bununla birlikte, diyabetle ilişkili diğer biyobelirteçler zayıf korelasyon göstermiştir; bu da diyabetik hastalarda yaşa bağlı sorunları ve araştırmaya duyulan ihtiyacı vurgulamaktadır.

Anahtar Kelimeler: Tip 2 diyabet, retinopati, nöropati, nefropati, idrar mikroalbümin-kreatinin oranı, protein-kreatinin oranı

Introduction

Type 2 diabetes mellitus (T2DM) is a growing global health concern, affecting over 500 million people worldwide and projected to rise further with an aging population [1]. The burden is especially high in older adults; for example, in Turkey nearly one-third of individuals over 65 have diabetes [2]. Chronic hyperglycemia in T2DM leads to widespread microvascular damage, giving rise to complications such as diabetic retinopathy (DR), nephropathy, and neuropathy [3]. These microvascular complications contribute substantially to morbidity, and their prevalence is striking – roughly one-third of T2DM patients develop DR, about one-quarter develop nephropathy, and nearly half develop neuropathy over time [1]. Elderly patients are particularly vulnerable to such complications due to longer disease duration and coexisting comorbidities, making early detection and prevention a clinical priority [4, 5].

One key approach to early detection of microvascular damage is monitoring urinary protein excretion. The urine albumin-to-creatinine ratio (ACR) is a simple and sensitive test for detecting microalbuminuria and early diabetic kidney disease, and guidelines recommend annual ACR screening in T2DM patients [6]. Recent studies have demonstrated that higher ACR correlates with increased risk of diabetic retinopathy and peripheral neuropathy [7, 8]. Similarly, the urine protein-to-creatinine ratio (PCR), which measures total proteinuria, is widely used to quantify renal involvement in diabetes; emerging evidence suggests that higher PCR values are linked to greater severity of diabetic retinopathy [9]. These findings underscore that albuminuria and proteinuria may serve as accessible markers reflecting systemic microvascular injury in diabetes.

Tight glycemic control remains fundamental in limiting microvascular complications. Landmark evidence indicates that each 1% reduction in hemoglobin A1c (HbA1c) can reduce the risk of microvascular complications by approximately 37% [10, 11]. Self-monitoring of blood glucose (SMBG) is an important tool for achieving and maintaining glycemic targets; frequent SMBG enables patients to adjust therapy and has been strongly associated with improved glycemic control [12]. Improved glycemic management in turn is known to slow the progression of complications such as DR, nephropathy, and neuropathy. However, in older adults, maintaining optimal glycemic control can be challenging, underscoring the need for reliable predictors and close monitoring of complications in this high-risk group.

Given the potential of these indicators, we hypothesize that elevated urinary ACR and PCR, as well as patterns of SMBG (reflecting glycemic control), are associated with the presence of microvascular complications in elderly T2DM patients. The aim of this study was to evaluate and compare the diagnostic performance of ACR, PCR, and SMBG in predicting diabetic retinopathy, nephropathy, and neuropathy in an elderly patient population.

Material and Methods

Ethics

This retrospective study was carried out at the Endocrinology and Metabolic Diseases Polyclinic in Karabük University between October 2021 to August 2023, adhering to the ethical principles outlined in the Declaration of Helsinki. Approval was obtained from the Non-Interventional Clinical Research Ethics Committee at Karabük University (Date: 10.09.2024, Decision No: 1876). Given the retrospective nature of the study, the Local Ethics Committee waived the requirement for informed consent.

Study Population

A total of 121 patients aged 65 or older and diagnosed with type 2 diabetes mellitus were retrospectively reviewed for eligibility during their outpatient clinic visits throughout the study period. The diagnosis and treatment of DM were carried out following American Diabetes Association (ADA) guidelines [13]. Exclusion criteria included severe cognitive or psychiatric conditions, absence of consistent clinical documentation, and end-stage renal failure unrelated to diabetes. After applying the exclusion criteria, 99 patients were included in the final analysis (Figure 1).

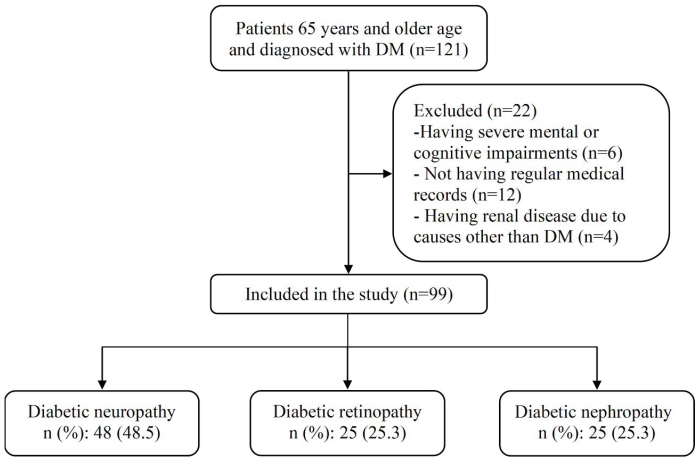

Figure 1. Flow diagram of the study

Data Collection

Demographic, clinical, anthropometric, and laboratory data were retrospectively obtained from electronic medical records. Body mass index (BMI) was calculated using recorded weight and height measurements. Waist and hip circumferences, as well as waist-to-hip ratio (WHR), were documented when available. Metabolic risk classifications based on waist circumference and WHR were defined according to the World Health Organization criteria [14]. For men, waist circumference greater than 94 cm waist circumference greater than 102 cm, and a waist-to-hip ratio equal to or greater than 0.90 had a substantial risk of metabolic complications. For women, a waist circumference greater than 80 cm showed an increased risk, while a waist circumference greater than 88 cm and waist-to-hip ratio equal to or greater than 0.85 had a significantly increased risk of metabolic complications.

Self-monitoring blood glucose (SMBG) values recorded by patients over the previous three months were retrospectively reviewed. The highest and lowest reported SMBG values were noted, and the difference between them (SMBGdiff), as well as the ratio of this difference to the highest value (SMBGratio), were calculated.

Biochemical parameters were obtained from patient records based on venous blood samples collected at the time of admission and were obtained from electronic medical records. Fasting glucose and triglyceride values were derived from serum samples, while urinary parameters were based on spot urine tests. Fasting samples were generally collected in the morning after at least 8 hours of fasting, as documented. The triglyceride glucose index (TyG) was calculated as: TyG = Ln (Fasting triglycerides [mg/dL] x Fasting blood glucose [mg/dL]/2). The urinary microalbumin-to-creatinine ratio (uMCR) and protein-to-creatinine ratio (uPCR) were calculated from recorded morning spot urine samples. Microalbuminuria was defined as having at least 2 out of 3 elevated uMCR values over a 3–6-month period, and the average of abnormal values was used for analysis. The averages of the abnormal values were calculated as: uMCR = Urinary microalbumin / Creatinine; uPCR = Urinary protein / Creatinine.

The presence of microvascular complications—diabetic neuropathy, retinopathy, and nephropathy—was determined based on clinical diagnoses documented in patient records. Each condition was defined according to established diagnostic guidelines [6].

Statistical analysis

Statistical analyses were performed using SPSS version 23 (IBM Corp. in Armonk, NY) and Medcalc version 16 (MedCalc Software Ltd, Ostend, Belgium). Numerical variables were assessed for normality using the Kolmogorov–Smirnov test. Those with normal distribution are presented as mean ± standard deviation, and those with non-normal distribution as median

[interquartile range (IQR): 25th–75th percentile]. Student's t-test was used for normally distributed data, while the Mann–Whitney U test was used for non-normally distributed data. Categorical data are expressed as numbers and percentages, with group comparisons conducted via Chi-square or Fisher's exact test. ROC curve analysis was used to assess diagnostic performance, with threshold values determined via the Youden index method. AUC curves were compared using a nonparametric approach, employing the generalized U-statistics method to estimate the covariance matrix, as previously described by DeLong et al. [15]. Significance was accepted at $P < 0.05$ (*) for all statistical analyses.

Results

Patients had a mean age of 71.2 ± 4.9 years, with the vast majority being male. The majority of the patients were males (n= 70, 70.7%) and were overweight (32.29±6.87). All patients were in the WC high-risk group, whereas only 33.3% presented a high risk for WHR. The treatment regimens were diverse; 56.6% were using a combination of an oral antidiabetic drug (OAD) and insulin, 23.3% only OAD, 13.1% only insulin, 4% were under combined treatment of GLP-1 agonist, OAD and insulin, 2% were using GLP-1 agonist and OAD, 1% were using GLP-1 agonist and insulin. The median peak self-monitored blood glucose (SMBG) level was 280 mg/dL (IQR: 200.0–398.0), while the median nadir glucose level was 110 mg/dL (IQR: 82.0–150.0). Hypertension was present in 73.7% of patients, and 55.6% had hyperlipidemia. The demographic characteristics of the patients are presented in detail in Table 1.

The laboratory characteristics of the patients are presented in Table 2. The median fasting and postprandial plasma glucose levels, as well as HbA1c values, were above reference ranges, indicating suboptimal glycemic control among the patients. The LDL cholesterol and triglyceride levels were also elevated in many cases. The mean TyG index was 5.1 (IQR: 4.82–5.22). Urinary markers showed a median MCR of 5.2 mg/g (IQR: 1.8–13.6) and PCR of 15.0 mg/g (IQR: 8.4–44.6). Additionally, vitamin D levels were low.

The diagnostic performance of the parameters is presented in Table 3 and Table 4. Among all parameters, only SMBGdiff was statistically significant in relation to neuropathy prediction; nevertheless, its diagnostic value was poor (AUC = 0.617, p = 0.040). SMBG difference and SMBG ratio were both statistically significant predictors of retinopathy (AUC = 0.625, p = 0.049; AUC = 0.656, p = 0.019), yet there was no meaningful difference in their diagnostic performance. In the prediction of retinopathy, both uMCR and uPCR ratios demonstrated statistical significance (AUC = 0.881, $p < 0.001$; AUC = 0.872, $p < 0.001$); nonetheless, their diagnostic accuracy was comparable (Table 3 and Figure 2). As presented in Table 4, an SMBG difference of >110.0 mg/dL was associated with a sensitivity of 79.2% and specificity of 51.0% for detecting diabetic neuropathy. For diabetic retinopathy, the optimal cut-off for SMBG difference was >123.0 mg/dL, yielding 84.0% sensitivity and 48.7% specificity. An SMBG ratio >0.61 showed lower diagnostic performance for retinopathy, with 60.0% sensitivity and 68.9% specificity. Regarding diabetic nephropathy, an uMCR cut-off of >10.3 mg/g demonstrated 76.0% sensitivity and 91.9% specificity. For uPCR, the cut-off value of >26.0 mg/g showed a sensitivity of 64.0% and specificity of 82.4% (Table 4).

Table 1. Demographics and clinical features of the patients.

Variables	All population n = 99
Age, years	71.2 ± 4.9
Gender, n (%)	
Female	29 (29,3)
Male	70 (70,7)
BMI, kg/m2	32.0 ± 6.3
WC, cm	
Female	121.2 ± 6.5
Male	110.4 ± 5.2
WC risk group, n (%)	
Normal	0
High	99 (100.0)
WHR	
Female	0.81 ± 0.02
Male	1.00 ± 0.02
WHR risk group, n (%)	
Normal	66 (66.7)
High	33 (33.3)
Duration of disease, years	13.0 (10.0-20.0)
Treatment regimen, n (%)	
OAD	23 (23.3)
Insulin	13 (13.1)
OAD and insulin	56 (56.6)
GLP-1 agonist and OAD	2 (2.0)
GLP-1 agonist and insulin	1 (1.0)
GLP-1 agonist, OAD and insulin	4 (4.0)
SMBG levelsa, mg/dL	
Lowest	110.0 (82.0-150.0)
Highest	280.0 (200.0-398.0)
Hypertension, n (%)	73 (73.7)
Hyperlipidemia, n (%)	55 (55.6)
Complications, n (%)	
Neuropathy	48 (48.5)
Retinopathy	25 (25.3)
Nephropathy	25 (25.3)

The data are expressed as the mean ± SD, median (IQR), or frequency (%). a Over the last three months. BMI: Body mass index, DM: Diabetes Mellitus, GLP-1: Glucagon-Like Peptide-1, OAD: Oral antidiabetic drug, SMBG: Self-monitoring of blood glucose, WC: Waist circumference, WHR: Waist-to-hip ratio.

Table 2. Laboratory findings of the patients.

Variables	Reference	Mean±SD or Median	IQR
Fasting plasma glucose, mg/dL	74.0-106.0	150.0	118.0-199.0
Postprandial plasma glucose, mg/dL	-	234.0	167.0-307.0
HbA1c, %	4.0-6.0	8.2 ± 1.8	7.0-9.1
Serum creatinine, mg/dL	0.50-1.30	0.95	0.74-1.20
GFR, mL/min/1.73 m^2		67.8 ± 23.3	52.0-88.0
AST, U/L	5.0-34.0	17.0	15.0-22.0
ALT, U/L	10.0-49.0	16.0	13.0-23.0
LDL cholesterol, mg/dL	60.0-140.0	93.8	74.0-125.0
HDL cholesterol, mg/dL	33.0-90.0	52.2 ± 14.4	42.0-58.8
Triglyceride, mg/dL	0.0-250.0	157.0	114.0-217.0
TyG index	-	5.1 ± 0.4	4.82-5.28
MCR, mg/g	-	5.52	2.90-12.39
PCR, mg/g	-	15.40	8.44-44.50
Uric acid, mg/dL	3.1-9.2	5.8 ± 1.8	4.5-6.6
TSH, uIU/mL	0.35-5.50	1.89	1.09-3.07
Vitamin B12, pg/mL	211.0-911.0	389.0	293.0-493.0
Vitamin D, ng/mL	30.0-100.0	16.6	10.8-23.1

The data are expressed as the mean ± SD, median (IQR).ALT: Alanine transaminase, AST: Aspartate transaminase, FIB-4 score: Fibrosis-4 score, GFR: Glomerular filtration rate, HbA1c: Hemoglobin A1c, HDL: High-density lipoprotein, IQR: Interquartile range, LDL: Low-density lipoprotein, MCR: Microalbumin-to-creatinine ratio, PCR: Protein-to-creatinine ratio, TSH: Thyroid-stimulating hormone, TyG index: Triglyceride-glucose index.

Table 3. ROC analysis results of HbA1c, TyG index, uMCR, uPCR, SMBG difference and SMBG ratio in estimating neuropathy, retinopathy and nephropathy.

	Neuropathy		Retinopathy		Nephropathy	
	AUC (95% CI)	p	AUC (95% CI)	p	AUC (95% CI)	p
HbA1c (%)	0.523 (0.421-0.625)	0.692	0.549 (0.446-0.649)	0.468	0.512 (0.409-0.614)	0.874
TyG index	0.597 (0.493-0.694)	0.091	0.536 (0.433-0.637)	0.601	0.540 (0.437-0.641)	0.570
uMCR	0.549 (0.445-0.649)	0.414	0.539 (0.436-0.640)	0.600	0.881 (0.801-0.938)	<0.001
uPCR	0.573 (0.469-0.672)	0.218	0.515 (0.413-0.617)	0.818	0.872 (0.790-0.931)	<0.001
SMBG difference	0.617 (0.514-0.713)	0.040	0.625 (0.522-0.721)	0.049	0.541 (0.438-0.642)	0.554
SMBG ratio	0.601 (0.497-0.698)	0.079	0.656 (0.554-0.749)	0.019	0.536 (0.433-0.637)	0.591

AUC: Area under the curve, CAD: Coronary artery disease, CI: Confidence interval, HbA1c: Hemoglobin A1c, SMBG: Self-monitoring of blood glucose, TyG index: Triglyceride-glucose index, uMCR: Urinary microalbumin-to-creatinine ratio, uPCR: Urinary protein-to-creatinine ratio.

Table 4. Associated cut-off values, sensitivity and specificity of uMCR, uPCR, SMBG difference and SMBG ratio in estimating diabetic neuropathy, retinopathy and nephropathy.

Variables	Cut-off	Sensitivity (95% CI)	Specificity (95% CI)
Neuropathy			
SMBG difference, mg/dL	>110.0	79.2 (65.0-89.5)	51.0 (36.6-65.2)
Retinopathy			
SMBG difference, mg/dL	>123.0	84.0 (63.9-95.5)	48.7 (36.9-60.6)
SMBG ratio	>0.61	60.0 (38.7-78.9)	68.9 (57.1-79.2)
Nephropathy			
uMCR, mg/g	>10.3	76.0 (54.9-90.6)	91.9 (83.2-97.0)
uPCR, mg/g	>26.0	84.0 (63.9-95.5)	82.4 (71.8-90.3)

CI: Confidence interval, SMBG: Self-monitoring of blood glucose, uMCR: Urinary microalbumin-to-creatinine ratio, uPCR: Urinary protein-to-creatinine ratio.

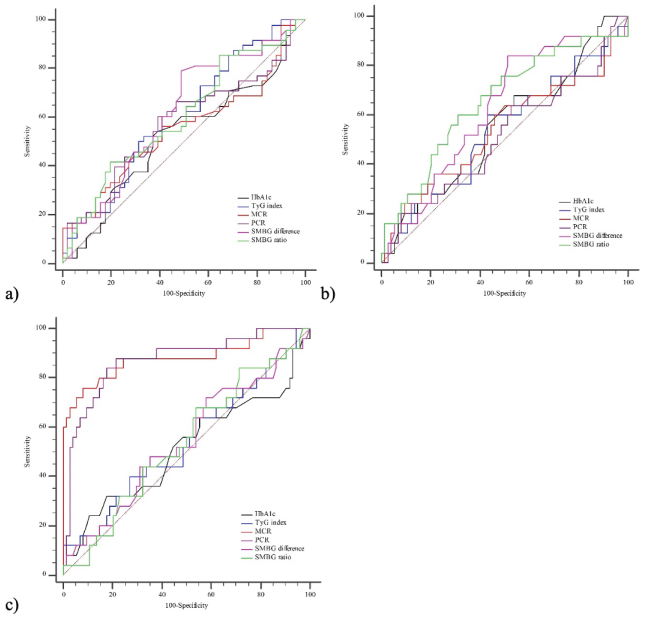

Figure 2. ROC curves of HbA1c, TyG index, uMCR, uPCR, SMBG difference and SMBG ratio in estimating (a) neuropathy, (b) retinopathy, and (c) nephropathy

Discussion

Our findings revealed a prevalence of 25% for retinopathy, 25% for nephropathy, and 48% for neuropathy among elderly diabetic patients—figures that closely mirror those reported in large-scale epidemiological studies. According to NHANES data, diabetic retinopathy affects 29–30% of individuals aged 65 and older [16], neuropathy is seen in 40–50% [17], and nephropathy prevalence ranges between 10–60% [16]. These high complication rates underscore the importance of identifying reliable predictive parameters for the early detection of microvascular complications in elderly patients with T2DM.

HbA1c is the established gold standard for evaluating long-term glycemic control and is commonly used in both diagnosis and complication risk assessment. While studies have demonstrated its predictive value for retinopathy and nephropathy in younger T1DM populations [18], and renal protection in older T2DM with lower HbA1c levels [19], our findings align with a Turkish cohort [20], showing no significant correlation between HbA1c and any microvascular complication.

The TyG index has emerged as a reliable surrogate marker for insulin resistance, a key pathophysiological component in the development of T2DM and its associated complications. Increasing evidence suggests that a higher TyG index is significantly associated with a greater risk of diabetic neuropathy [21], nephropathy [22, 23], and retinopathy [23], positioning it as a potential early indicator of microvascular dysfunction. Despite its growing recognition in the literature, our study did not find a statistically significant association between the TyG index and the presence of microvascular complications in elderly patients with T2DM. One possible explanation for this discrepancy is the older age profile of our cohort compared to previous studies, which often involved younger or mixed-age populations. Aging is associated with increased comorbidity burden, altered metabolic responses, and a higher likelihood of preexisting overlapping complications, all of which may confound the independent predictive value of the TyG index.

Studies have shown age-related differences in microvascular complications in T2DM patients [24]. Urinary biomarkers, uMCR, and uPCR are non-invasive markers that reflect renal function and early kidney damage. Our results confirm that uMCR is a highly sensitive indicator for diabetic nephropathy in elderly patients, detecting renal microvascular damage often before overt clinical symptoms. This is in agreement with current guidelines, which prefer uMCR for early diabetic kidney disease screening due to its superior sensitivity at low levels of proteinuria [25]. Also, Our findings align with the current literature, studies from Italy [25] and Brazil [26] comprised of T2DM patients with kidney disease showed elevated albuminuria in those older than 75 years. In fact, the cumulative incidence of ESRD climbs steeply as one moves from mild to heavy albuminuria [27]. The uPCR, which captures total protein excretion, similarly tracked nephropathy severity in our study. Elevated uPCR levels were associated with nephropathy, which is consistent with literature noting that uPCR rises in parallel with declining glomerular filtration and can serve as a convenient marker of kidney damage [25].

Self-monitoring of blood glucose metrics, reflecting glycemic control, also showed expected trends: our patients with DR had higher blood glucose profiles, mirroring the well-established relationship between chronic hyperglycemia and retinopathy [28]. Our findings concur with a longitudinal study in older adults where regular SMBG use was linked to ~50% reduced incidence of DR [29], suggesting that intensive self-monitoring (and presumably better glucose management) can translate into lower retinopathy risk. Also, Tight glycemic control remains the only proven strategy to prevent or delay

diabetic neuropathy [30]. Recent studies have expanded this understanding by implicating glycemic variability as well—high glucose oscillations correlate with painful neuropathy and reduced nerve function [31]. Our data did hint at this, as individuals with stable SMBG trends tended to report less neuropathic pain, aligning with emerging literature on variability's role. However, the diagnostic performance of the SMBGratio, as indicated by its moderate to low area under the ROC curve, implies that while it provides valuable information, its ability to serve as an independent predictor is limited. The poor reliability and discriminatory power in the clinical setting were in line with the current literature [32].

Limitations

The study has several limitations. The cross-sectional design of the study limits our ability to determine causality or temporal relationships between diagnostic factors and the development of complications. Our sample size was small, which may limit the statistical power to detect associations between complications and biomarkers, especially for those with modest effects. The presence of multiple coexisting complications and comorbidities in the elderly may have confounded the observed relationships, masking potential associations between traditional biomarkers (e.g., HbA1c, TyG index) and microvascular damage. The reliance on single measurements for some biomarkers may not fully capture the dynamic nature of glycemic control and its impact on the development of complications. Future longitudinal studies with larger cohorts are needed to further elucidate these relationships and refine screening strategies, ultimately improving clinical outcomes in this vulnerable population.

Conclusion

Our results suggest that in elderly patients with type 2 diabetes, urinary biomarkers such as uMCR and uPCR provide strong diagnostic accuracy for nephropathy compared to traditional glycemic markers and insulin resistance indices. While SMBGratio shows promise in detecting retinopathy, its stand-alone predictive performance is limited. These findings highlight the need for a tailored, multi-marker approach to assessing microvascular complications in the elderly, taking into account the unique pathophysiological changes associated with aging.

Ethics Committee Approval

The study was conducted with the permission of the Karabük University's Non-Interventional Clinical Research Ethics Committee (Date: 10.09.2024, Decision No: 1876).

Informed Consent

Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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