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Glycated Albumin and Hba1c for the Diagnosis of Prediabetes in Obese and Non-obese Individuals

Obez ve Obez Olmayan Bireylerde Prediyabet Tanısında Glikozile Albümin ve Hba1c

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Abstract

Objective: In our study, we examined whether glycated albumin (GA) had any superiority over the HbA1c test in detecting individuals with insulin resistance, prediabetes, and diabetes in obese and non-obese groups. This study is the first to examine the diagnostic power of HbA1c and GA tests alone or together for prediabetes, diabetes, and insulin resistance in non-obese and obese individuals.

Materials and Methods: The study was conducted at Ankara Yıldırım Beyazıt University Faculty of Medicine and Atatürk Training and Research Hospital. Individuals were divided into three groups: diabetes, prediabetes, and insulin resistance, which were further sub-grouped as obese and non-obese according to their body mass index values.

Results: When we examined the HbA1c and GA values in the diabetes, prediabetes, and insulin resistance groups, we found significantly higher rates of correct detection of prediabetes and diabetes (sensitivity) for GA than for HbA1c in non-obese individuals. The specificity of GA was lower than HbA1c in these non-obese individuals, whereas the specificity of GA was similar to HbA1c in obese individuals. Our data show that in non-obese individuals, GA measurement is a more sensitive but less specific tool compared with the measurement of HbA1c. Therefore, we suggest that, while HbA1c and GA were in agreement with oral glucose tolerance test and fasting glucose levels in the diagnosis of diabetes in obese individuals ($p<0.05$), GA alone or together with HbA1c may be a valuable tool in the diagnosis of prediabetes and diabetes in non-obese individuals.

Conclusion: This study shows that GA levels have higher sensitivity and lower specificity than HbA1c in the diagnosis of type 2 diabetes in non-obese individuals.

Keywords: Prediabetes, diabetes mellitus, glycated albumin, HbA1c

Öz

Amaç: Çalışmamızda obez ve obez olmayan gruplarda insülin direnci, prediyabet ve diyabeti tespit etmede glikozillenmiş albüminin (GA) HbA1c testine üstünlüğü olup olmadığını inceledik. Bu çalışma, obez olmayan ve obez bireylerde prediyabet, diyabet ve insülin direnci için tek başına veya birlikte HbA1c ve GA testlerinin tanısal gücünü inceleyen ilk çalışmadır.

Gereç ve Yöntemler: Çalışma Ankara Yıldırım Beyazıt Üniversitesi Tıp Fakültesi ve Atatürk Eğitim ve Araştırma Hastanesi'nde gerçekleştirilmiştir. Bireyler önce diyabet, prediyabet, insülin direnci ve daha sonra vücut kitle indeksi değerlerine göre obez ve obez olmayanlar alt gruplara ayrıldı.

Bulgular: Diyabet, prediyabet ve insülin direnci gruplarında HbA1c ve GA değerlerini incelediğimizde; obez olmayan bireylerde HbA1c'ye kıyasla GA için prediyabet ve diyabetin (hassasiyet) doğru saptanma oranlarının önemli ölçüde daha yüksek olduğunu bulduk. Obez olmayan bu bireylerde GA'nın özgüllüğü HbA1c'den düşükken, obezlerde GA'nın özgüllüğü HbA1c'ye benzerdi. Verilerimiz obez olmayan bireylerde GA ölçümünün HbA1c ölçümüne kıyasla daha duyarlı ancak daha az spesifik bir araç olduğunu göstermektedir. Bu nedenle şunları öneriyoruz; obez bireylerde diyabet tanısında HbA1c ve GA, OGTT ve açlık glukoz düzeyleri ile uyumlu iken ($p<0,05$), GA tek başına veya HbA1c ile birlikte obez olmayan bireylerde prediyabet ve diyabet tanısında değerli bir araç olabilir.

Sonuç: Bu çalışma, obez olmayan bireylerde tip 2 diyabet tanısında GA düzeylerinin HbA1c'den daha yüksek duyarlılığa ve daha düşük özgüllüğe sahip olduğunu göstermektedir.

Anahtar Kelimeler: Prediyabet, diyabet, glikozile albumin, HbA1c

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Introduction

Prediabetes term is used for individuals whose glucose levels do not meet the criteria for diabetes but are too high to be considered normal (1). Fasting plasma glucose level (FPG) values between 100-125 mg/dL are defined as IFG, and values with a plasma glucose level of 140-199 mg/dL after 75 grams of oral glucose in the second hour are defined as impaired glucose tolerance (IGT). Patients with these values are included in the prediabetic group. Besides, oral glucose tolerance test (OGTT) and HbA1c are equally valuable in the diagnosis of prediabetes. Patients with an HbA1c level of 5.7-6.4% are also considered prediabetic. Other glycated proteins such as glycated albumin (GA) as measures of average glycemia are also available, however, their diagnostic and prognostic significance are not as clear as for HbA1c. HbA1c predicts glycemia over the past (2-3) months, whereas glycated albumin (GA), an early Amadori-type glycation protein of the non-enzymatic glycation reaction between glucose and serum albumin, indicate glycemic status for the past (2-3) weeks (2,3). Glycated albumin, reflecting short term glycaemia and is not affected by many conditions that alter HbA1c. The GA level is calculated as a percentage by dividing the amount of glycated albumin by total albumin (4). Obesity, an important risk factor in diabetes development, has been shown to affect the test results used in the diagnosis and follow-up of prediabetes. Body mass index (BMI) is the most practical step to assess the degree of overweight and obesity. Effective interventions for weight loss favourably increase insulin sensitivity (5,6). In our study, assessed the diagnostic power of HbA1c and GA tests alone or together for prediabetes, insulin resistance and diabetes in non-obese and obese individuals.

Materials and Methods

The study was conducted at Atatürk Taining and Research Hospital and Dr. Rıdvan Ege Hospital. This research was approved by the Ethical Committee at Yıldırım Beyazıt University (protocol no: 2017/23, date: 10.08.2017). We obtained signed informed consent from all participants.

Study Population and Design

Patients (n=126) diagnosed either with diabetes, prediabetes and insulin resistance were selected among the patients who attended the Internal Diseases and Endocrinology outpatient clinics, considering the indications for OGTT. Patients with severe hepatic and renal dysfunction, pregnancy, malabsorption syndrome, steroid or alpha-glucosidase inhibitor use, patients with a history of gastrectomy, and other endocrine and metabolic disorders such as thyroid disease and metabolic syndrome were excluded. The demographic information and anthropometric measurements were recorded. The waist circumference [midway between the lowest rib and the iliac crest in a standing position, as recommended by the World Health Organization (WHO)] measured. The BMI of patients participating in the study were evaluated using a bioimpedance device TANITA (7). BMI ≥ 30 kg/m^2 was accepted as obese according to the WHO classification (8).

Sample Collection and Storage

Blood samples from individuals for analyses of routine and specific parameters were collected into yellow top blood tubes without anticoagulant (BD Vacutainer®) or lavender top blood tubes containing 5.4 mg K2-EDTA (BD Vacutainer®). Fasting blood samples were drawn between 8.00 to 10.00 am. after overnight fasting of 8-12 h. For postprandial glucose measurement, blood sample were taken two hours after the meal. All serum samples were processed within two hours of blood collection and one aliquot for glycated albumin was stored at -80 ˚C until the day of analysis.

Glucose Tolerance Testing

In cases with insulin resistance and prediabetes clinic, OGTT was performed as a follow-up. Individuals were given 75 grams of glucose, and OGTT and simultaneous insulin measurements were performed in blood samples taken at 0, 30, 60, 90 and 120th minutes, respectively. OGTT results of the cases were evaluated according to American Diabetes Association criteria (1). Individuals were then divided into 3 groups; diabetes, prediabetes and insulin resistance which further sub-grouped obese and non-obese according to their OGTT results and BMI values. These groups are shown below:

Group 1: Obese, prediabetes

Group 2: Non-obese, prediabetes

Group 3: Obese, insulin resistant

Group 4: Non-obese, insulin resistant

Group 5: Obese, Diabetes

Group 6: Non-Obese, diabetes

Laboratory Analyses

Blood glucose levels were measured using Roche Cobas 501 device by spectrophotometric method. Serum albumin levels were measured using Roche Cobas 501 device by immune-turbidimetric method. Haemoglobin was measured by the impedance and flow-cell method in the Sysmex 2100 device. Insulin levels were measured with Roche Cobas 600 ECLIA method simultaneously with OGTT (at 0, 30, 60, 90, and 120 minutes). Insulin resistance of the individuals was evaluated using the formula (HOMA-IR = FPG (mg/dL) x fasting plasma insulin (microunit/mL)/405) and HOMA-IR >2.5 accepted as insulin resistance (6-9). HbA1c was measured in the same whole blood samples by ion exchange chromatographic HPLC method using Agilent 1100 Series device (NGSP-certified). The results were given as % Hb. Serum glycated albumin (GA) was measured with a commercially available kit, DIAZYME Glycated Serum Protein Assay by enyzmatic method, using Cobas 501 device. % GA was calculated using the equation; glycated

albumin (%) =2.9 + {[glycated albumin concentration (g/dL): total albumin concentration (g/dL)]: 1.4} * 100. The inter-assay CVs for GA was 1.7% at 0.58 g/L and 4.5% at 1.67g/L.

Gycated albumin (%) =2.9 + {[glycated albumin concentration (g/dL): total albumin concentration (g/dL)]: 1.4} * 100.

Statistical Analysis

IBM-SPSS Statistics 21.0 for Windows program was used for statistical analysis. P<0.05 was accepted as statistically significant. The compliance of numerical variables examined in the study to normal distribution was examined with the Shapiro-Wilks normality test and normality plots. Mean ± standard deviation, median, minimum, and maximum values were used to display the descriptive statistics of the variables. Frequencies and percentages were given in categorical variables. The correlation between BMI and HbA1c and GA was analysed with the Spearman rho correlation coefficient. Mann-Whitney U and Kruskal-Wallis tests were used for comparing independent groups. Pearson chi-square test result was given for categorical variables. The "HUM" package in the R program was used to determine the cut-off points for discriminating the class with GA (9). Correct classification probabilities (CCP) and 95% confidence intervals were obtained for the groups from 3x3 cross tables according to the cut-off points determined for GA and specified for HbA1c. The calculated CCP1, CCP2, and CCP3 values are the probability of determining those with insulin resistance (specificity), prediabetes (intermediate fraction), and diabetes (sensitivity). In the case of using GA and HbA1c together, an ordinal logistic model was used to determine the class determination ability. CCP and 95% confidence limits were calculated according to the classes determined as a result of the model. The comparison of the CCP determined by the variables was Performed with the McNemar-Bowker test.

Results

Descriptive Properties of Patients and Blood Chemistry Values

Among patients involved in the study, 42.9 % were male (n=54) and 57.1 % were female (n=72). Median age was 49 (18; 76). Descriptive properties and blood chemistry values of individuals, grouped according to diabetes status, were summarized in Table 1. Diagnoses as insulin resistance, prediabetes and diabetes were defined by the endocrinology specialist, according to the fasting glucose levels and OGTT results of the individuals (Table 1). Gender distribution in and among insulin resistance, prediabetes and diabetes groups were similar (p=0.131). HbA1c (%) and GA (%) levels were highest in diabetes and lowest in insulin resistance groups (p<0.001). Pairwise comparison showed that GA values in diabetic patients were significantly higher than those with insulin resistance and prediabetes (p<0.05).

Test results of individuals were also grouped according to their BMI categories (Table 2). Obesity was more prominent in females, compared to males and the gender distributions of the BMI categories were not similar between the two groups (p<0.001). Glucose and postprandial blood glucose levels did not differ in obese and non-obese patients (p>0.05).

Predictive Value of HbA1c and GA Alone or Together in Patients

HbA1c levels <5.7% were classified as "insulin resistant", between 5.7-6.4% as "prediabetes" and ≥6.5% as "diabetes" groups (10). Patients with GA values <12.81% were accepted as "insulin resistant", between 12.81-16.06% as "prediabetes" and ≥16.07% as "diabetes" groups (14). Groups for HbA1c and GA were determined using an ordinal logistic regression model and the correct classification rates using HbA1c (%) and GA (%) were given in Table 3. We observed that an agreement with the clinician's diagnosis

Table 1. Biochemical tests according to diabetes categories

Variable	Insulin resistance	Prediabetes	Diabetes	Z, χ^2	p-value
BMI (kg/m²)	33.95 (24.3; 45)	30.4 (21.9; 47.7)	30.2 (19.6; 50.8)	3.876	0.144
Glucose (mg/dL)	89 (65; 116)[a]	103 (80; 137)[b]	138 (89; 322)[c]	70.189	**<0.001**
Postprandial glucose (mg/dL)	100 (68; 151)[a]	117 (60; 200)[a]	215 (75; 521)[b]	63.350	**<0.001**
HbA1c (%)	5.34 (3.96; 6.66)[a]	5.39 (4.46; 7)[a]	6.87 (4.49; 11.45)[b]	55.094	**<0.001**
Albumin (g/dL)	4.69 (4.16; 5.36)	4.63 (3.51; 5.32)	4.63 (4.12; 5.41)	0.454	0.797
GA (mmol/L)	237.25 (180.8; 304.2)[a]	270.6 (174.5; 373.1)[a]	366.3 (244.1; 1116)[b]	71.388	**<0.001**
GA (%)	12.36 (10.01; 15.28)[a]	13.86 (11.03; 17.83)[a]	18.08 (12.73; 48.07)[b]	71.478	**<0.001**
HGB (g/dL)	14.55 (12.4; 17.5)	14.7 (11.4; 17)	14.5 (9.2; 17.2)	0.045	0.978

Data were summarized as frequency (percentage) and or median (minimum; maximum). The Kruskal-Wallis test (χ^2) for more than two groups, Mann-Whitney U test (Z) for two groups and Pearson chi-square test (χ^2) results were reported for quantitative and qualitative variables, respectively. Bold type p-values were lower than 0.05. a,b,c Values were similar in groups denoted by the same letter. BMI: Body mass index, GA: Glycated albumin, HGB: Hemoglobin

was obtained with laboratory results, when HbA1c + GA is used together. In non-obese group, while HbA1c had higher specificity compared to GA in diagnosis, it was GA, alone or in combination with HbA1c, was found to be the more sensitive test in diagnosis (Table 3).

When HbA1c (%) and GA (%) measurements were applied for diabetes classification and compared with the diagnosis made by the clinician, an agreement in diagnosis was achieved only in the obese group (p=0.064) (Table 4). On the other hand, in the non-obese group, the diabetes classifications were found to be in agreement with the clinician's diagnosis, only when GA values [alone or combined with HbA1c (%) values] were applied (p=0.317) (Table 4).

In our study, in the prediabetes group, 16 out of 31 individuals were classified as prediabetic by GA measurements alone

Table 2. Biochemical tests of individuals according to BMI categories categories

Variable	Total	Non-obese	Obese	χ^2; Z	p-value
Diabetes n (%)					
Insulin resistance	32 (25.4)	13 (23.6)	19 (26.8)	0.164	0.921
Prediabetes	31 (24.6)	14 (25.5)	17 (23.9)		
Diabetes	63 (50.0)	28 (50.9)	35 (49.3)		
BMI (kg/m²)	30.5 (19.6; 50.8)	27.4 (19.6; 29.8)	35.1 (30.0; 50.8)	-9.605	**<0.001**
Glucose (mg/dL)	110 (65; 322)	109 (65; 322)	112 (73; 320)	-1.279	0.201
Postprandial blood glucose (mg/dL)	135 (60; 521)	141 (71; 521)	133 (60; 414)	-0.620	0.535
HbA1c (%)	5.88 (3.96; 11.45)	5.76 (4.27; 10.35)	6.01 (3.96; 11.45)	-1.552	0.121
Albumin (g/dL)	4.65 (3.51; 5.41)	4.68 (4.12; 5.41)	4.63 (3.51; 5.36)	-1.065	0.287
Serum GA (mmol/L)	302.4 (174.5; 1116.0)	302.4 (187.3; 1116)	302.4 (174.5; 856)	-0.497	0.619
GA (%)	14.74 (10.01; 48.07)	15.03 (10.35; 48.07)	14.61 (10.01; 38.43)	-0.401	0.688
HGB (g/dL)	14.6 (9.2; 17.5)	15.2 (11.4; 17.2)	14.1 (9.2; 17.5)	-3.752	**<0.001**

Data were summarized as frequency (percentage) or median (minimum; maximum). The Mann-Whitney U test (Z) and Pearson chi-square test (χ^2) results were reported for quantitative and qualitative variables, respectively. Bold type p-values were lower than 0.05. BMI: Body mass index, GA: Glycated albumin, HGB: Hemoglobin

Table 3. Correct classification probabilities for HbA1c (%), GA (%) and HbA1c (%) + GA (%)

		Insulin resistance	Prediabetes	Diabetes	
		Specificity CCP1 (min. and max. limits of 95% CI)	Intermediate fraction CCP2 (min. and max. limits of 95% CI)	Sensitivity CCP3 (min. and max. limits of 95% CI)	p-value*
Total	**HbA1c**	81.3 (67.7; 94.8)	29.0 (13.1; 45.0)	58.7 (46.6; 70.9)	**<0.001**
	GA	62.5 (45.7; 79.3)	74.2 (58.8; 89.6)	74.6 (63.9; 85.4)	**0.010**
	HbA1c + GA	62.5 (45.7; 79.3)	71.0 (55.0; 86.9)	76.2 (65.7; 86.7)	0.057
Non-obese	**HbA1c**	84.6 (65.0; 99.9)	28.6 (4.9; 52.2)	42.9 (24.5; 61.2)	**0.002**
	GA	38.5 (12.0; 64.9)	64.3 (39.2; 89.4)	67.9 (50.6; 85.2)	**0.037**
	HbA1c + GA	38.5 (12.0; 64.9)	64.3 (39.2; 89.4)	60.7 (42.6; 78.8)	**0.017**
Obese	**HbA1c**	78.9 (60.6; 97.3)	29.4 (7.8; 51.1)	71.4 (56.5; 86.4)	0.053
	GA	78.9 (60.6; 97.3)	82.4 (64.2; 99.9)	80.0 (66.8; 93.3)	0.155
	HbA1c + GA	78.9 (60.6; 97.3)	76.5 (56.3; 96.6)	88.6 (78.0; 99.1)	0.940

CCP: Correct classification probability, CI: Confidence interval, GA: Glycated albumin. *In McNemar-Bowker test results, when the p-value was higher than 0.05, it means that there was an agreement between the classification based on the related variable (only HbA1c, only GA or HbA1c + GA) and the actual classes. P-value lower than 0.05 means no agreement

and 9 by HbA1c test with/without GA test. On the other hand, in the diabetes group, 14 out of 63 individuals classified as diabetic by GA test alone and 37 individuals by HbA1c with/without GA test. The diabetic group defined by using GA also had lower BMI (Table 5).

Discussion

HbA1c and fasting blood glucose are equally effective screening tools to detect type 2 diabetes. In the diagnosis of prediabetes, OGTT and HbA1c levels are also regularly used. In recent years, the superiority of different glycosylated proteins such as GA over HbA1c values in detecting individuals with prediabetes has been in discussion. Obesity, an important risk factor in diabetes development, has been shown to affect the test results used in the diagnosis and follow-up of prediabetes (6,7).

In our study, we examined whether GA had any superiority over HbA1c test in detecting individuals with insulin resistance, prediabetes and diabetes in obese and non-obese groups. To the best of our knowledge, this study is the first to examine the diagnostic power of HbA1c and GA tests alone or together for prediabetes, diabetes and insulin resistance in non-obese and obese individuals. Koga et al. (11) showed that HbA1c was not always an ideal glycemic control index and does not accurately reflect the status of plasma glucose control in various pathological conditions. HbA1c levels may be falsely high in hemolytic anemia, blood loss, splenomegaly, iron deficiency anemia, vitamin B12 deficiency, severe hypertriglyceridemia, and uremia (12). Therefore, measurements may need to be validated by different methods or to be evaluated using different diabetes biomarkers.

In this study, we also examined the HbA1c and GA values of individuals in the prediabetes and diabetes groups, which were grouped according to fasting blood glucose and OGTT values, alone or together. When GA and HbA1c values were evaluated without considering BMI, GA values were

Table 4. Comparison of correct classification probabilities obtained by only HbA1c (%), only GA (%) and HbA1c (%) + GA (%) in BMI groups

	HbA1c - GA	HbA1c - HbA1c + GA	GA - HbA1c + GA
	p-value	p-value	p-value
Total	**<0.001**	**<0.001**	0.317
Non-obese	**<0.001**	**<0.001**	0.317
Obese	0.064	**0.003**	**0.025**

McNemar-Bowker test results. When the p-value was higher than 0.05, it means that there was an agreement between the classifications based on the related variables. p-value lower than 0.05 means no agreement. BMI: Body mass index, GA: Glycated albumin

Table 5. Comparison of demographic characteristics patients and biochemical parameters determined as prediabetic and diabetic using HbA1c and GA levels alone

Diagnosed by clinician (n)	Prediabetes (31)		p-value	Diabetes (63)		p-value
Classified by HbA1c and/or GA (n)	HbA1c or HbA1c and GA (9)	GA (15)		HbA1c or HbA1c and GA (37)	GA (14)	
BMI (kg/m²)	29.9 (23.1; 47.7)	31.9 (25.4; 37.4)	0.640	32.4 (19.6; 50.8)	27.6 (22.0; 39.3)	**0.023**
Glucose (mg/dL)	109 (86; 121)	98 (80; 117)	0.108	168 (89; 322)	117 (100; 189)	**0.001**
Postrandial glucose (mg/dL)	124 (94; 194)	114 (60; 182)	0.290	250 (83; 521)	189 (94; 311)	**0.014**
HbA1c (%)	5.9 (5.7; 6.4)	5.1 (4.5; 5.6)	**<0.001**	7.60 (6.6; 11.4)	6.11 (4.53; 6.47)	**<0.001**
GA (%)	13.9 (12.5; 16.9)	13.7(12.9; 15.0)	0.519	19.92 (13.9;48.1)	17.27 (16.07; 22.14)	**0.020**

Data were summarized as frequency (percentage) and or median (minimum; maximum). The Mann-Whitney U test (Z) and Pearson chi-square test (χ^2) results were ported for quantitative and qualitative variables, respectively. Bold type p-values were lower than 0.05. BMI: Body mass index, GA: Glycated albumin

higher in the diabetes group compared to the other groups ($p<0.001$). In line with our study, a study conducted by Hsu et al. (13) in which GA and HbA1c were compared for diabetes screening, reported a significant positive correlation among FPG, GA, and HbA1c levels. Other researchers reported that GA better reflects glycemic control and is a better marker in diabetes screening compared to the gold standard HbA1c in some patient groups (14). A study by Kengne et al. (15) examining the OGTT, HbA1c, GA and fructosamine values in prediabetes and diabetes patients in an African population where sickle cell anemia, human immunodefiency virus and chronic kidney diseases are common, showed that IGT detected by OGTT test is more compatible with GA values than HbA1c. Shima et al. (16) reported that a single random measurement of GA is more useful than HbA1c for screening for diabetes in the population, but neither of these two parameters is sensitive enough to detect individuals with IGT.

Studies have proven a strong relationship between BMI and diabetes and insulin resistance (17,18). Non-obese type 2 diabetes phenotype is characterized by disproportionately reduced insulin secretion and less insulin resistance, compared to obese patients with type 2 diabetes. We detected significantly lower fasting blood glucose levels ($p=0.001$), postprandial blood sugar levels ($p=0.014$), BMI ($p=0.023$) and waist circumference ($p=0.046$) values in the group with diabetes classified by GA against the group classified as diabetes by HbA1c test. Supporting our data, Sumner et al. (19) found that the BMI values of the prediabetes group based on GA values were lower than the group based on HbA1c values. On the other hand, Koga et al. (11,20) showed a negative correlation between obesity and serum glycated albumin and a positive correlation between BMI and HbA1c, whilst there was a negative correlation between BMI and GA in non-diabetic subjects. The same group revealed by multivariate regression analyses that BMI was the strongest negative variable for GA. A study by Nishimura et al. (21) reported that when the relationship between BMI and HbA1c and GA is examined, a significant positive correlation between BMI and HbA1c, and a significant negative correlation were observed between BMI and GA. Similar to the literature, in our study, GA levels were slightly lower in obese individuals than in non-obese individuals, however, this value was not statistically significant ($p=0.688$). We did not observe any statistical difference between obese and non-obese individuals in terms of HbA1c values. On the other hand, we found significantly higher rates of correct detection of prediabetes and diabetes (sensitivity) for GA compared to HbA1c in non-obese individuals. The specificity of GA was lower than HbA1c in these non-obese individuals whereas the specificity of GA was similar to HbA1c in obese ones.

Our data show that in non-obese individuals, GA measurement is a more sensitive but less specific tool compared to measurement of HbA1c and is not affected by many conditions that alter HbA1c. Therefore, we suggest that; while HbA1c and GA were in agreement with OGTT and fasting glucose levels in diagnosis of diabetes in obese individuals ($p<0.05$), GA alone or together with HbA1c may be a valuable tool in diagnosis of prediabetes and diabetes in non-obese individuals.

Conclusion

This study shows that GA levels have higher sensitivity but lower specificity than HbA1c in the diagnosis of type 2 diabetes in non-obese individuals. There are some limitations in our study. First, our study was a cross-sectional study and the number of subjects in this study is relatively small. Secondly, since our study was conducted in a single centre. Nevertheless, this study provides important information about the tests of choice for diagnosing prediabetes and diabetes in obese and non-obese individuals. Improving diagnostic sensitivity with the combined use of HbA1c and GA may be useful in detecting diabetes earlier in non-obese individuals and taking preventive measures.

Ethics

Ethics Committee Approval: This research was approved by the Ethical Committee at Yıldırım Beyazıt University (protocol no: 2017/23, date: 10.08.2017).

Informed Consent: We obtained signed informed consent from all participants.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: R.A., A.Ş., L.D.K., Concept: R.A., A.Ş., T.Ç., R.E., L.D.K., Design: R.A., T.Ç., L.D.K., Data Collection or Processing: R.A., P.D., R.E., L.D.K., Analysis or Interpretation: R.A., P.D., A.Ş., T.Ç., L.D.K., Literature Search: R.A., P.D., T.Ç., L.D.K., Writing: R.A., L.D.K.

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