Received: 11 July 2022 | Revised: 15 August 2022 | Accepted: 27 August 2022

DOI: 10.1002/jcla.24693

RESEARCH ARTICLE

WILEY

# The usefulness of the estimated average glucose/fasting blood glucose ratio for pancreatic β-cell function assessment in hyperglycemia during health checkups

Eun-Hee Nah[1] | Seon Cho[1] | Hyeran Park[1] | Suyoung Kim[1] | Eunjoo Kwon[1] | Han-Ik Cho[2]

[1]Health Promotion Research Institute, Korea Association of Health Promotion, Seoul, South Korea

[2]MEDIcheck LAB, Korea Association of Health Promotion, Seoul, South Korea

**Correspondence**
Eun-Hee Nah, Health Promotion Research Institute, Korea Association of Health Promotion, Seoul, South Korea.
Emails: cellonah@hanmail.net; cellonah@kahp.or.kr

## Abstract

**Background:** Type 2 diabetes (T2DM) is a disease marked by inadequate insulin secretion by pancreatic beta-cell function (BCF) failure and insulin resistance (IR). Assessing and managing the BCF and IR should be started early to prevent or delay the progression of the disease. The aim of this study was to determine the usefulness of the estimated average glucose (eAG)/fasting blood glucose (FBG) ratio for pancreatic BCF in hyperglycemia.

**Methods:** This cross-sectional study consecutively selected 10,594 subjects who underwent a health checkup at 16 health checkup centers in 13 Korean cities between 2019 and 2021. The subjects consisted of 3003 patients with normoglycemia, 3413 with impaired fasting glucose and 4178 with T2DM. The eAG was calculated using Nathan's regression equation. BCF and IR were estimated by the homeostasis model assessment (HOMA)-β and HOMA-IR, respectively. Multivariate (adjusted) regression analysis was performed to evaluate the association between the eAG/FBG ratio and HOMA.

**Results:** The median values among FBG groups for the eAG/FBG ratio, HOMA-β, -IR and insulin differed significantly ($p < 0.001$). The second-, third- and fourth-quartile groups of the eAG/FBG ratio had positive higher correlation coefficients [9.533, 10.080 and 12.021, respectively (all $p < 0.001$)] for HOMA-β than the first quartile group, and higher negative coefficients for HOMA-IR [−0.696, −0.727 and −0.598, respectively (all $p = 0.001$)].

**Conclusion:** The eAG/FBG ratio was significantly correlated with both HOMA-β and -IR, which suggests that eAG/FBG ratio reveals BCF and IR in hyperglycemia. Measurement of this ratio could be useful for monitoring BCF and IR in prediabetes and T2DM.

KEYWORDS
eAG/FBG ratio, homeostasis model assessment, insulin resistance, pancreatic β-cell function, type 2 diabetes

## 1 | INTRODUCTION

Type 2 diabetes (T2DM) is a chronic disease characterized by insulin resistance (IR) in tissue and incompetent compensatory insulin secretion by pancreatic beta-cell dysfunction.[1–3] Once insulin secretion by pancreatic beta-cell can no longer compensate for the tissue IR, hyperglycemia becomes clinically apparent and deterioration of beta-cell reserve is accelerated. Early intervention should be needed during the process of disease to prevent or delay progression of the disease and its complications, evade complete beta-cell function (BCF) failure, and revoke IR. For interventions early in the progression of the disease, diagnostic methods for assessing BCF and IR are needed in diabetes and even in prediabetes.

The fundamental status of glucose tolerance in hyperglycemia has been estimated by various diagnostic methods.[4] The homeostasis model assessment (HOMA) has been introduced to evaluate the association between glucose and insulin balance during fasting.[5–7] The endogenous glucose output and insulin secretion by pancreatic beta-cell regulate basal blood glucose concentration. HOMA-β therefore estimates BCF by calculating the ratio of fasting insulin to fasting glucose concentrations. HOMA-IR, which is an index of fasting IR, is evaluated by reversed calculation of this.

Fasting blood glucose (FBG) and glycated hemoglobin (HbA1c) are considered as the main indicators for assessing glycemic control in chronic hyperglycemia.[8] HbA1c-derived estimated average glucose (eAG) is also an easier parameter to help people with hyperglycemia to understand their average daily glucose level.[9] A few studies have evaluated the association between the eAG/FBG ratio and glucose tolerance,[10,11] but they have investigated restricted age groups such as childhood and young adults with diabetes. Moreover, the numbers of individuals with diabetes have not been sufficient, which may make their findings about the association between the eAG/FBG ratio and HOMA unreliable. This study therefore aimed to determine the usefulness of the HbA1c-derived eAG/FBG ratio for pancreatic BCF in prediabetes and T2DM at health checkups.

## 2 | MATERIALS AND METHODS

### 2.1 | Study subjects

This cross-sectional, retrospective study consecutively selected subjects who underwent either voluntary or obligatory national health checkups at 16 health checkup centers in 13 Korean cities between January 2019 and July 2021. The study subjects consisted of 3003 patients with normoglycemia, 3413 with impaired fasting glucose (IFG) and 4178 with T2DM. The guidelines of the American Diabetes Association defined IFG and T2DM.[12] The medical records of the subjects were reviewed. The study was approved by the institutional review board of the Korea Association of Health Promotion (Approval No. 130750-202109-HR-007). The requirement for informed consent was waived because of the retrospective design of the study, and the analysis used anonymized clinical data.

### 2.2 | Laboratory measurements

Venous blood was drawn during each health checkup after an overnight fast. Fasting serum glucose, triglycerides, high-density lipoprotein-cholesterol and creatinine were measured using the Hitachi 7600 analyzer (Hitach). HbA1c levels were measured using ion-exchange high-performance liquid chromatography with the Tosoh HLC-723G8 analyzer (Tosoh). Serum insulin was measured using the electrochemiluminescence immunoassay with the Cobas e801 device (Roche Diagnostics).

### 2.3 | Calculation of quartiles of eAG/FPG ratio, HOMA-β and HOMA-IR

The eAG was calculated as eAG (mmol/L) = 1.59 × HbA1c (%) − 2.59.[9] The eAG/FBG ratio was calculated as eAG/FBG ratio = eAG level (mmol/L)/FBG level (mmol/L). The eAG/FBG ratios were divided into 4 quartile groups from quartile 1 (Q1) to quartile 4 (Q4). A quartile is a type of quantile which divides the number of datasets into four parts, or quarters. The data were ordered from smallest to largest to compute quartiles. The first quartile (Q1) is defined as the lowest or 25th percentile. The second quartile (Q2) is between the 25th percentile and median of the dataset. The third quartile (Q3) is between the median and the 75th percentile of the dataset. The fourth quartile (Q4) is the upper or 75th percentile of the dataset.

HOMA-β and HOMA-IR were calculated using the following formulas[5,6]:

$$\text{HOMA} - \beta = \left[20 \times \text{fasting insulin level } (\mu\text{U}/m\text{L})\right] / \left[\text{FBG (mmol/L)} - 3.5\right].$$

$$\text{HOMA} - \text{IR} = \left[\text{fasting insulin level } (\mu\text{U}/m\text{L}) \times \text{FBG (mmol/L)}\right] / 22.5.$$

### 2.4 | Statistical analyses

Statistical analyses were performed using SAS version 9.4 for Windows (SAS Institute), and statistical significance was set at $p < 0.05$. Comparisons of variables according to their fasting glucose levels and the quartile (Q) group of the eAG/FBG ratio were analyzed using either ANOVA or chi-square tests. Scheffe's test was used for multiple comparison. Linear regression analysis was used to determine the correlations of the eAG/FPG ratio with HOMA-β and HOMA-IR. Age, sex and waist circumference were included as variables in the multivariable regression analysis to determine the associations of the eAG/FBG ratio with HOMA-β and HOMA-IR. Mann–Whitney *U* test was used to determine the difference in median values in each FBG group.

## 3 | RESULTS

### 3.1 | Characteristics of study subjects according to FBG group

A total of 10,594 subjects were in this study. The mean age of the subjects in this study was 54.0 ± 12.3 years (range: 20–91 years). The eAG levels were 7.32 ± 1.09 mmol/L, 9.22 ± 1.83 mmol/L, and 14.90 ± 2.79 mmol/L in the IFG group, and FBG 6.99–11.10 mmol/L and FBG >11.10 mmol/L groups, respectively. The eAG/FBG ratios were significantly decreased as FBG increased ($p < 0.001$). Those with higher FBG had increased serum insulin levels compared with those with normal FBG ($p < 0.001$). The mean HOMA-β values were significantly lower in the prediabetes and diabetes groups ($p < 0.001$), while those of HOMA-IR were significantly higher in those groups ($p < 0.001$) (Table 1). Figure 1 shows box plots of the eAG/FBG ratio, HOMA-β, HOMA-IR and insulin according to FBG level. The median values among FBG groups for the eAG/FBG ratio, HOMA-β, HOMA-IR and insulin differed significantly ($p < 0.001$) (Figure 1).

### 3.2 | HOMA-β and HOMA-IR according to quartiles of eAG/FBG ratio in prediabetes and diabetes

The eAG/FBG ratios were divided into 4 quartile groups from quartile 1 (Q1) to quartile 4 (Q4). Mean eAG/FBG ratios in Q1, Q2, Q3 and Q4 were 0.95, 1.08, 1.18 and 1.36, respectively. FBG significantly decreased as the quartile of eAG/FBG ratio increased ($p < 0.001$). HOMA-β was significantly increased, whereas HOMA-IR was significantly decreased among the higher quartiles of the eAG/FBG ratio compared with the first quartile (both $p < 0.001$) (Table 2).

### 3.3 | Linear regression analyses of the eAG/FBG ratio with HOMA-β and HOMA-IR in prediabetes and diabetes

Figure 2 shows scatter plots of the eAG/FBG ratio versus HOMA-β and HOMA-IR in prediabetes and diabetes. HOMA-β and HOMA-IR had positive and negative correlations with the eAG/FBG ratio, respectively ($r^2 = 0.015$ and $p < 0.001$, and $r^2 = 0.010$ and $p < 0.001$, respectively) (Figure 2).

### 3.4 | Multivariable regression analyses of the eAG/FBG ratio with HOMA-β and HOMA-IR in prediabetes and diabetes

Multivariable regression analyses indicated that the second-, third- and fourth-quartile groups of the eAG/FPG ratio had positive higher correlation coefficients [9.533, 10.080 and 12.021, respectively (all $p < 0.001$)] for HOMA-β than the first quartile group, and higher negative coefficients for HOMA-IR [−0.696, −0.727 and −0.598, respectively (all $p = 0.001$)] (Table 3).

## 4 | DISCUSSION

This study has revealed HOMA-β and HOMA-IR progression along with the eAG/FBG ratio for various levels of FBG, and that the eAG/FBG ratio has positive and negative correlations with HOMA-β and HOMA-IR, respectively. While HOMA-β was significantly higher in higher quartile groups of the eAG/FBG ratio compared with the first quartile, HOMA-IR was significantly lower. These results suggest that the eAG/FBG ratio reflects HOMA-β and HOMA-IR in adult prediabetes and T2DM.

Comprehension of the pathophysiologic mechanism of T2DM is important in the treatment of the disease. The process of disease already starts with IR before clinically apparent hyperglycemia. This IR is compensated by appropriate compensation of pancreatic beta-cell insulin hypersecretion. However, some degree of beta-cell dysfunction has already also been reflected. With further BCF deterioration, which is characterized by a progressive failure of BCF to maintain normoglycemia, hyperglycemia has manifested clinically.[13–16] Our study presented BCF and IR through HOMA according to FBG levels, which reflected T2DM progression. While HOMA-β gradually decreased as IFG levels increased, HOMA-IR gradually increased. Serum insulin also increased with HOMA-IR. It was particularly interesting that the insulin levels were lower in individuals with severe diabetes (with FBG >11.10 mmol/L) than in individuals with FBG = 6.99–11.10 mmol/L. This may reflect further BCF deterioration in severe diabetes.

HbA1c testing is the principal tool for evaluating chronic hyperglycemic control, and has a strong predictive value for diabetes complications.[17–19] The HbA1c-derived eAG estimates average glucose levels, which could inform individuals with hyperglycemia about their glycemic control.[9] Some studies reported that the correlation between HbA1c-derived eAG and FBG depended on the level of glycemic control.[20,21] Kim et al.[21] demonstrated that the correlation between eAG and FBG decreased in well-controlled diabetic patients. They also demonstrated that large differences between eAG and FBG in well-controlled diabetic patients might reflect the higher contribution of postprandial glucose in these patients than in poorly controlled diabetics, whereas the small differences between eAG and FBG in poorly controlled patients might reflect the higher contribution of FBG in these patients than in well-controlled patients. These findings supported our results that the eAG/FBG ratio was significantly decreased as FBG increased.

The present study investigated the association between the eAG/FBG ratio and HOMA in adult prediabetes and T2DM. Higher quartile groups of the eAG/FBG ratio had significantly higher HOMA-β and significantly lower HOMA-IR compared with the first

**TABLE 1** Characteristics of study subjects according to fasting plasma glucose group

| | | Fasting blood glucose | | | | | |
|---|---|---|---|---|---|---|---|
| | All ($n = 10,594$) | <100 mg/dl[a] (<5.55 mmol/L) ($n = 3003$) | 100–125 mg/dl[b] (5.55–6.94 mmol/L) ($n = 3413$) | 126–200 mg/dl[c] (6.99–11.10 mmol/L) ($n = 3387$) | >200 mg/dl[d] (>11.10 mmol/L) ($n = 791$) | *p* value | Multiple comparisons |
| Age, year | 53.97 ± 12.31 | 48.32 ± 12.83 | 57.14 ± 11.15 | 56.80 ± 11.07 | 49.65 ± 11.22 | <0.001 | a < d < b, c |
| Sex, male | 6290 (59.4) | 1351 (45.0) | 2040 (59.8) | 2363 (69.8) | 536 (67.8) | <0.001 | |
| SBP, mmHg | 121.11 ± 15.77 | 116.18 ± 13.99 | 124.79 ± 14.94 | 131.27 ± 15.70 | 131.45 ± 18.89 | <0.001 | a < b < c, d |
| DBP, mmHg | 76.23 ± 10.47 | 73.53 ± 9.61 | 78.38 ± 9.97 | 81.24 ± 10.57 | 83.40 ± 13.52 | <0.001 | a < b < c < d |
| BMI, kg/m$^2$ | 24.90 ± 3.91 | 24.03 ± 3.61 | 25.97 ± 3.54 | 26.71 ± 5.11 | 26.24 ± 3.51 | <0.001 | a < b, c, d |
| WC, cm | 83.80 ± 10.40 | 81.21 ± 10.08 | 87.14 ± 9.52 | 89.58 ± 9.56 | 88.64 ± 9.83 | <0.001 | a < b, c, d |
| Hb, g/L | 144.47 ± 15.96 | 141.31 ± 16.09 | 145.30 ± 14.65 | 148.24 ± 15.54 | 155.34 ± 15.57 | <0.001 | a < b < c < d |
| FBG, mmol/L | 7.11 ± 2.56 | 5.02 ± 0.35 | 6.21 ± 0.42 | 8.20 ± 1.04 | 14.20 ± 2.49 | <0.001 | a < b < c < d |
| HbA1c, % | 6.79 ± 1.68 | 5.58 ± 0.48 | 6.23 ± 0.68 | 7.43 ± 1.15 | 11.00 ± 1.76 | <0.001 | a < b < c < d |
| Insulin, μU/mL | 7.28 ± 5.80 | 5.39 ± 3.85 | 7.40 ± 5.60 | 8.80 ± 6.73 | 7.49 ± 6.47 | <0.001 | a < b, d < c |
| eAG, mmol/L | 8.20 ± 2.68 | 6.28 ± 0.77 | 7.32 ± 1.09 | 9.22 ± 1.83 | 14.90 ± 2.79 | <0.001 | a < b < c < d |
| eAG/FPG ratio | 1.17 ± 0.18 | 1.26 ± 0.17 | 1.18 ± 0.16 | 1.12 ± 0.17 | 1.06 ± 0.17 | <0.001 | d < c < b < a |
| Creatinine, μmol/L | 84.44 ± 18.42 | 82.51 ± 19.21 | 86.23 ± 17.36 | 86.70 ± 17.87 | 80.37 ± 17.04 | <0.001 | a, d < b, c |
| eGFR, ml/min/1.73m$^2$ | 82.09 ± 15.20 | 83.25 ± 14.56 | 80.02 ± 15.04 | 80.38 ± 16.01 | 91.18 ± 17.13 | <0.001 | b < a < d |
| TG, mmol/L | 1.80 ± 1.78 | 1.33 ± 1.24 | 1.79 ± 1.42 | 2.22 ± 2.09 | 3.22 ± 3.36 | <0.001 | a < b < c < d |
| HDL-C, mmol/L | 1.33 ± 0.34 | 1.44 ± 0.35 | 1.30 ± 0.32 | 1.24 ± 0.31 | 1.23 ± 0.34 | <0.001 | c, d < b < a |
| HOMA-β | 50.63 ± 154.02 | 67.75 ± 282.54 | 55.58 ± 41.83 | 38.78 ± 30.06 | 15.01 ± 14.37 | <0.001 | d < c < a, b |
| HOMA-IR | 2.38 ± 2.30 | 1.21 ± 0.88 | 2.05 ± 1.59 | 3.22 ± 2.55 | 4.63 ± 3.93 | <0.001 | a < b < c < d |
| Metabolic syndrome* | 1631 (15.4) | 172 (5.7) | 750 (22.0) | 563 (16.6) | 146 (18.5) | <0.001 | |

*Note*: Data are mean ± standard deviation or *N* (%) values. *p* value from one-way ANOVA or chi-square test. The significant intergroup difference based on Scheffe's multiple comparison test. Metabolic syndrome: conforming with three or more NCEP-ATPIII criteria. Central obesity: males, WC ≥ 90 cm; females, WC ≥ 85 cm. Hyperglycemia: ≥5.6 mmol/L. Hypertension: systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg or taking blood pressure medicine. Decreased HDL-C: males, ≤1.0 mmol/L; females, ≤1.3 mmol/L.

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; Hb, hemoglobin; HbA1c, glycated hemoglobin, eAG, estimated average glucose; HDL-C, high-density lipoprotein cholesterol; HOMA, homeostasis model assessment; SBP, systolic blood pressure; TG, triglycerides; WC, waist circumference.

*NCEP-ATPIII criteria.

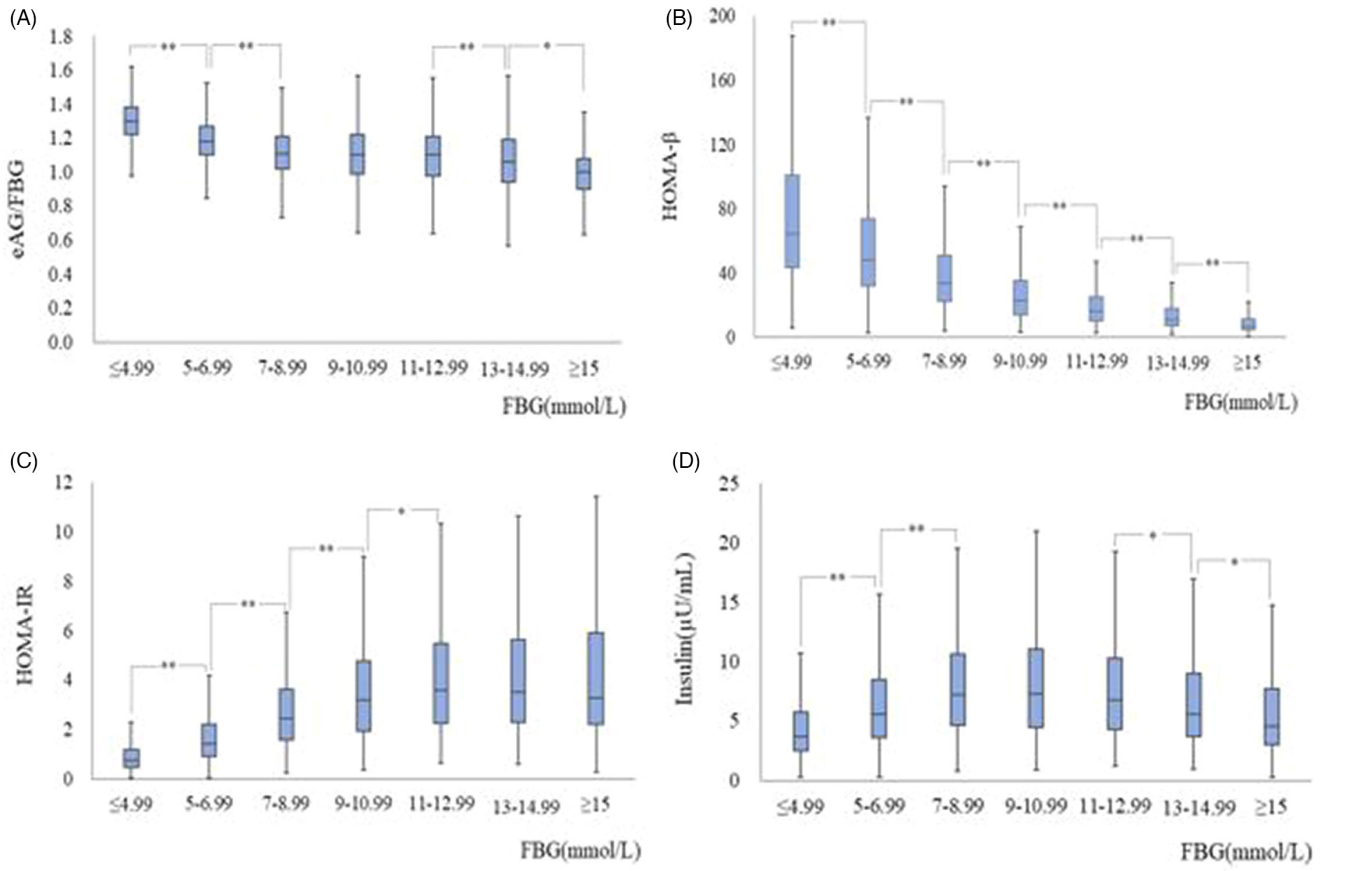


**FIGURE 1** Box plots of the (A) eAG/FBG ratio, (B) HOMA-β, (C) HOMA-IR and (D) insulin according to fating blood glucose level. Box limits and horizontal lines within boxes represent interquartile ranges and the median, respectively. The upper and lower whiskers indicate the 97.5th and 2.5th percentiles, respectively. The difference in median values in each FPG group was determined using the Mann–Whitney *U* test: $^{*}p < 0.01$; $^{**}p < 0.001$.

quartile. A study of childhood diabetes[10] found that HOMA-β levels were significantly higher in T2DM with higher eAG/FBG ratios than in T2DM with lower eAG/FBG ratios; however, HOMA-IR was not correlated with eAG/FBG ratio. On the other hand, Guo et al.[11] reported that the eAG/FBG ratio was negatively associated with HOMA-IR level, but not significantly associated with HOMA-β in young adult with T2DM. These discrepancies may be attributed to differences in age distribution and diabetes severity, or small numbers of subjects. The present study demonstrated consistently significant associations of the eAG/FBG ratio with HOMA-β and HOMA-IR after adjusting for age, sex and waist circumference in a large population with prediabetes or T2DM. These results suggest that the eAG/FBG ratio reflects HOMA-β and HOMA-IR in adult prediabetes and T2DM.

Our study has some limitations. First, due to the cross-sectional study, the causal relationship between the eAG/FBG ratio and BCF and IR could not be evaluated. Second, HOMA was used to evaluate BCF and IR. While HOMA model is convenient and relatively simple, its results are less sensitive in evaluating BCF changes and pancreatic reserve by itself alone.[22,23] However, regarding diabetes management, early interventions via combining lifestyle modifications and multiple drugs are the optimal way to delay the development and progression of the disease.[24,25] For optimal treatment strategies for individual patients with T2DM and prediabetes, early diagnostic evaluations of residual BCF and IR of the patient are needed. In routine clinical and laboratory examinations, HOMA helped to assess BCF and IR in hyperglycemia.[4–7] Lastly, although the eAG/FBG ratio had positive and negative correlations with HOMA-β and HOMA-IR, these correlations were small. Nevertheless, the HbA1-derived eAG/FBG ratio could be a reliable complementary to the HOMA-β and HOMA-IR in assessment of pancreatic β-cell function in prediabetes and patients with T2DM who have only undergone FBG and HbA1c tests in a health checkup.

In conclusion, it is too late to act once pancreatic BCF has been irreversibly deteriorated in diabetes. The ultimate goal is to delay the clinically apparent hyperglycemia and the progression of apparent diabetes and its complications. Furthermore, an early diagnosis of the degree and rate of BCF deterioration through estimation of the eAG/FBG ratio using routine measurements such as FBG and HbA1c-derived eAG could provide a meaningful method to manage prediabetes and patients with T2DM who have only undergone FPG and HbA1c tests.

**TABLE 2** Clinical and laboratory characteristics in the subjects according to the eAG/FBG quartile group in prediabetes and T2DM

| | | eAG/FBG ratio | | | | | |
|---|---|---|---|---|---|---|---|
| | All ($n$ = 7591) | Q1 (≤1.0382) ($n$ = 1899) | Q2 (1.0383–1.1306) ($n$ = 1885) | Q3 (1.1307–1.2327) ($n$ = 1910) | Q4 (≥1.2328) ($n$ = 1897) | $p$ value | Multiple comparisons |
| eAG/FPG ratio | 1.14 ± 0.17 | 0.95 ± 0.08 | 1.08 ± 0.03 | 1.18 ± 0.03 | 1.36 ± 0.15 | <0.001 | Q1 < Q2 < Q3 < Q4 |
| FBG, mmol/L | 7.93 ± 2.58 | 9.07 ± 3.33 | 7.80 ± 2.40 | 7.46 ± 2.06 | 7.40 ± 1.95 | <0.001 | Q3, Q4 < Q2 < Q1 |
| HbA1c, % | 7.26 ± 1.75 | 7.00 ± 1.83 | 6.94 ± 1.63 | 7.14 ± 1.52 | 7.96 ± 1.80 | <0.001 | Q2 < Q3 < Q4 |
| eAG, mmol/L | 8.96 ± 2.78 | 8.54 ± 2.91 | 8.44 ± 2.59 | 8.77 ± 2.42 | 10.07 ± 2.87 | <0.001 | Q2 < Q3 < Q4 |
| Age, year | 56.21 ± 11.35 | 54.65 ± 11.28 | 55.64 ± 11.43 | 56.96 ± 11.09 | 57.57 ± 11.37 | <0.001 | Q1, Q2 < Q3, Q4 |
| Sex, male | 4939 (65.1) | 1398 (73.6) | 1268 (67.3) | 1176 (61.6) | 1097 (57.8) | <0.001 | |
| SBP, mmHg | 127.14 ± 15.74 | 130.22 ± 16.07 | 126.45 ± 15.13 | 126.15 ± 15.58 | 125.84 ± 15.92 | <0.001 | Q2, Q3, Q4 < Q1 |
| DBP, mmHg | 79.55 ± 10.52 | 82.29 ± 11.22 | 79.17 ± 10.29 | 79.14 ± 10.06 | 77.50 ± 9.98 | <0.001 | Q2, Q3, Q4 < Q1 |
| BMI, kg/m$^2$ | 26.16 ± 3.98 | 26.65 ± 4.95 | 25.80 ± 3.49 | 26.03 ± 3.29 | 26.27 ± 4.22 | 0.028 | Q2 < Q1 |
| WC, cm | 87.81 ± 9.59 | 89.21 ± 9.17 | 87.34 ± 8.89 | 87.15 ± 9.29 | 87.74 ± 11.08 | 0.021 | Q2 < Q1 |
| Hb, g/L | 147.24 ± 15.32 | 150.92 ± 14.72 | 148.01 ± 14.37 | 146.10 ± 14.93 | 143.72 ± 16.46 | <0.001 | Q4 < Q2, Q3 < Q1 |
| Insulin, μU/mL | 8.03 ± 6.25 | 8.38 ± 6.66 | 7.90 ± 6.19 | 7.68 ± 5.40 | 8.16 ± 6.67 | 0.004 | Q2 < Q1 |
| Creatinine, μmol/L | 86.01 ± 17.60 | 87.13 ± 17.60 | 87.17 ± 17.79 | 85.98 ± 16.13 | 83.73 ± 18.70 | 0.001 | Q4 < Q1, Q2 |
| eGFR, mL/min/1.73m$^2$ | 80.86 ± 15.76 | 82.79 ± 16.27 | 80.83 ± 15.70 | 79.58 ± 13.99 | 80.34 ± 16.95 | 0.010 | Q3 < Q1 |
| TG, mmol/L | 2.08 ± 1.98 | 2.39 ± 2.42 | 2.10 ± 1.84 | 1.85 ± 1.47 | 2.00 ± 2.05 | <0.001 | Q3 < Q2 < Q1 |
| HDL-C, mmol/L | 1.27 ± 0.32 | 1.29 ± 0.36 | 1.27 ± 0.31 | 1.28 ± 0.30 | 1.23 ± 0.31 | <0.001 | Q4 < Q1, Q2, Q3 |
| HOMA-β | 43.86 ± 37.03 | 37.60 ± 33.23 | 43.77 ± 35.27 | 45.11 ± 35.15 | 48.95 ± 42.86 | <0.001 | Q1 < Q2, Q3 < Q4 |
| HOMA-IR | 2.84 ± 2.51 | 3.39 ± 3.12 | 2.74 ± 2.42 | 2.56 ± 1.95 | 2.67 ± 2.33 | <0.001 | Q2, Q3, Q4 < Q1 |
| Metabolic syndrome | 1459 (19.2) | 383 (20.2) | 377 (20.0) | 354 (18.5) | 345 (18.2) | 0.293 | |

*Note*: Data are mean ± standard deviation or *N* (%) values. $p$ value from one-way ANOVA or chi-square test. The significant intergroup difference based on Scheffe's multiple comparison test.

Abbreviations: Q1, quartile 1; Q2, quartile 2; Q3, quartile 3; Q4, quartile.

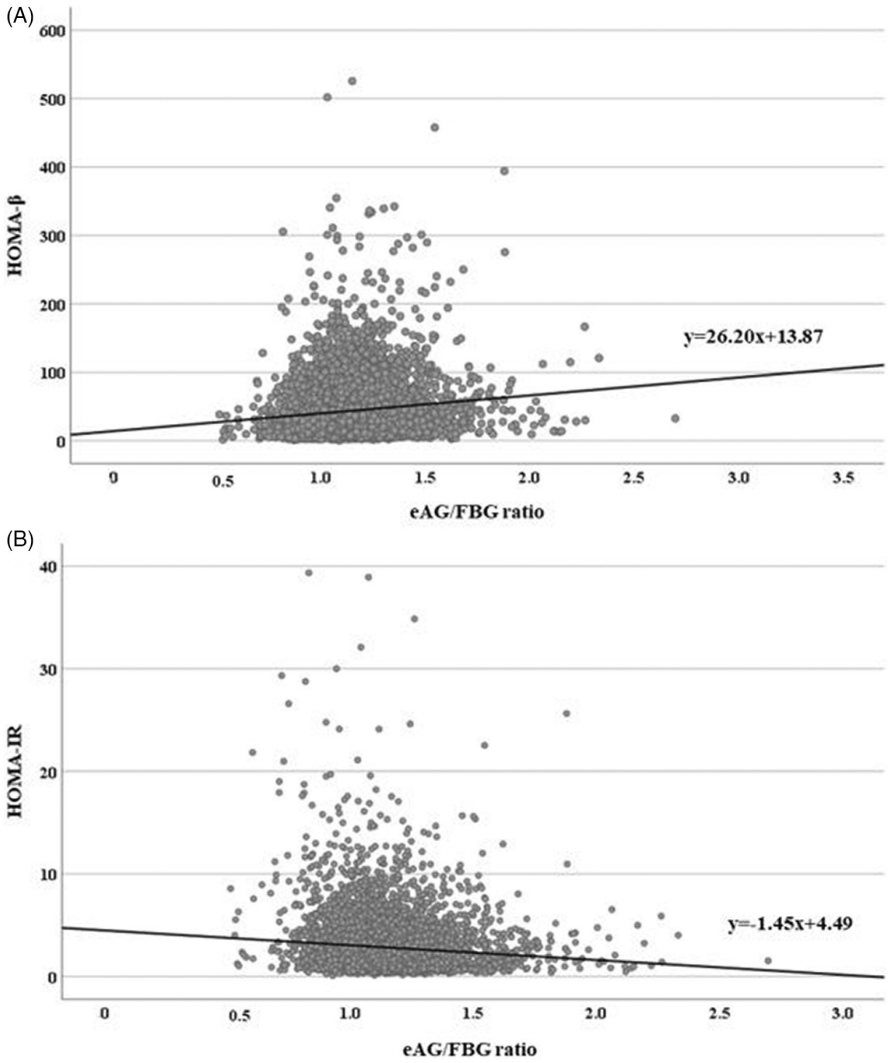


**FIGURE 2** Scatter plots between eAG/FBG ratio and (A) HOMA-β ($r^2 = 0.015$, $p < 0.001$) and (B) HOMA-IR ($r^2 = 0.010$, $p < 0.001$) in prediabetes and T2DM.

**TABLE 3** Multivariable regression for the variables effect of HOMA- β and HOMA-IR in prediabetes and T2DM

| | HOMA-β | | | | HOMA-IR | | | |
|---|---|---|---|---|---|---|---|---|
| | Univariate | | Multivariable | | Univariate | | Multivariable | |
| | Coefficient (*SE*) | *p* value | Coefficient (*SE*) | *p* value | Coefficient (*SE*) | *p* value | Coefficient (*SE*) | *p* value |
| Age | −0.504 (0.037) | <0.001 | −0.886 (0.094) | <0.001 | −0.058 (0.002) | <0.001 | −0.028 (0.005) | <0.001 |
| Sex | 5.646 (0.889) | <0.001 | 16.341 (2.306) | <0.001 | 0.059 (0.061) | 0.331 | 0.686 (0.132) | <0.001 |
| eAG/FBG group | | | | | | | | |
| Q2 | 6.172 (1.197) | <0.001 | 9.533 (2.896) | 0.001 | −0.645 (0.081) | <0.001 | −0.696 (0.166) | <0.001 |
| Q3 | 7.516 (1.193) | <0.001 | 10.080 (2.936) | 0.001 | −0.831 (0.081) | <0.001 | −0.727 (0.168) | <0.001 |
| Q4 | 11.352 (1.195) | <0.001 | 12.021 (3.176) | <0.001 | −0.721 (0.081) | <0.001 | −0.598 (0.182) | 0.001 |
| WC | 1.648 (0.113) | <0.001 | 1.835 (0.114) | <0.001 | 0.095 (0.016) | <0.001 | 0.100 (0.007) | <0.001 |

Abbreviations: eAG, estimated average glucose; FBG, fasting plasma glucose; HOMA, homeostasis model assessment; *SE*, standard error; WC, waist circumference.

## AUTHOR CONTRIBUTIONS

**Conceptualization:** Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim, Eunjoo Kwon, Han-Ik Cho. **Data curation:** Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim. **Formal analysis**: Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim, Eunjoo Kwon. **Investigation**: Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim, Eunjoo Kwon, Han-Ik Cho. **Methodology:** Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim, Eunjoo Kwon, Han-Ik Cho. **Project administration:** Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim, Eunjoo Kwon, Han-Ik Cho. **Resources:** Eun-Hee Nah, Seon Cho, Hyeran Park,

Suyoung Kim, Eunjoo Kwon. **Supervision:** Eun-Hee Nah, Han-Ik Cho. **Validation:** Eun-Hee Nah, Seon Cho, Hyeran Park, Suyoung Kim, Han-Ik Cho. **Writing – original draft:** Eun-Hee Nah. **Writing – review & editing:** Eun-Hee Nah, Seon Cho, Han-Ik Cho.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included in the article.

## ORCID

*Eun-Hee Nah* https://orcid.org/0000-0003-0637-4364

## REFERENCES

1. Kahn SE. The relative contributions of insulin resistance and beta-cell dysfunction to the pathophysiology of type 2 diabetes. *Diabetologia*. 2003;46:3-19.
2. Roden M, Shulman GI. The integrative biology of type 2 diabetes. *Nature*. 2019;576:51-60.
3. Stumvoll M, Goldstein BJ, van Haeften TW. Type 2 diabetes: principles of pathogenesis and therapy. *Lancet*. 2005;365:1333-1346.
4. Cersosimo E, Solis-Herrera C, Trautmann ME, Malloy J, Triplitt CL. Assessment of pancreatic β-cell function: review of methods and clinical applications. *Curr Diabetes Rev*. 2014;10:2-42.
5. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*. 1985;28:412-419.
6. Mojiminiyi OA, Abdella NA. Effect of homeostasis model assessment computational method on the definition and associations of insulin resistance. *Clin Chem Lab Med*. 2010;48:1629-1634.
7. Wallace TM, Levy JC, Matthews DR. Use and abuse of HOMA modeling. *Diabetes Care*. 2004;27:1487-1495.
8. Consensus Committee. Consensus statement on the worldwide standardization of the hemoglobin A1c measurement: the American Diabetes Association, European Association for the Study of Diabetes, International Federation of Clinical Chemistry and Laboratory Medicine, and the International Diabetes Federation. *Diabetes Care*. 2007;30:2399-2400.
9. Nathan DM, Kuenen J, Borg R, Zheng H, Schoenfeld D, Heine RJ. A1c-derived average glucose study group. translating the A1C assay into estimated average glucose values. *Diabetes Care*. 2008;3:1473-1478.
10. Lee JE, Lee JW, Fujii T, Fujii N, Choi JW. The ratio of estimated average glucose to fasting plasma glucose level is superior to glycated albumin, hemoglobin A1c, fructosamine, and GA/A1c ratio for assessing β-cell function in childhood diabetes. *Biomed Res Int*. 2014;2014:370790.
11. Guo J, Lei S, Zhou Y, Pan C. The ratio of estimated average glucose to fasting plasma glucose level as an indicator of insulin resistance in young adult diabetes: an observational study. *Medicine (Baltimore)*. 2020;99:e22337.
12. American Diabetes Association. Standards of medical care in diabetes–2011. *Diabetes Care*. 2011;34(Suppl 1):S11-S61.
13. Weyer C, Bogardus C, Mott DM, Pratley RE. The natural history of insulin secretory dysfunction and insulin resistance in the pathogenesis of type 2 diabetes mellitus. *J Clin Invest*. 1999;104:787-794.
14. Cerf ME. Beta cell dysfunction and insulin resistance. *Front Endocrinol (Lausanne)*. 2013;4:37.
15. Zheng Y, Ley SH, Hu FB. Global aetiology and epidemiology of type 2 diabetes mellitus and its complications. *Nat Rev Endocrinol*. 2018;14:88-98.
16. Simonson GD, Kendall DM. Diagnosis of insulin resistance and associated syndromes: the spectrum from the metabolic syndrome to type 2 diabetes mellitus. *Coron Artery Dis*. 2005;16:465-472.
17. Laiteerapong N, Ham SA, Gao Y, et al. The legacy effect in type 2 diabetes: impact of early glycemic control on future complications (The Diabetes & Aging Study). *Diabetes Care*. 2019;42:416-426.
18. Stratton IM, Adler AI, Neil HA, et al. Association of glycaemia with macrovascular and microvascular complications of type 2 diabetes (UKPDS 35): prospective observational study. *BMJ*. 2000;321:405-412.
19. Little RR, Rohlfing CL, Sacks DB. National Glycohemoglobin Standardization Program (NGSP) Steering Committee. Status of hemoglobin A1c measurement and goals for improvement: from chaos to order for improving diabetes care. *Clin Chem*. 2011;57:205-214.
20. Sriwimol W, Choosongsang P, Choosongsang P, Petkliang W, Treerut P. Association between HbA1c-derived estimated average glucose and fasting plasma glucose in patients with normal and abnormal hemoglobin patterns. *Scand J Clin Lab Invest*. 2022;82:192-198.
21. Kim HY, Kim SY, Suh S, et al. The relationship between estimated average glucose and fasting plasma glucose. *Clin Chem Lab Med*. 2013;51:2195-2200.
22. Chang AM, Smith MJ, Bloem CJ, Galecki AT, Halter JB, Supiano MA. Limitation of the homeostasis model assessment to predict insulin resistance and beta-cell dysfunction in older people. *J Clin Endocrinol Metab*. 2006;91:629-634.
23. Bergman RN, Zaccaro DJ, Watanabe RM, et al. Minimal model-based insulin sensitivity has greater heritability and a different genetic basis than homeostasis model assessment or fasting insulin. *Diabetes*. 2003;52:2168-2174.
24. American Diabetes Association. Standards of medical care in diabetes-2013. *Diabetes Care*. 2013;36(Suppl 1):S11-S66.
25. Defronzo RA. Banting Lecture. From the triumvirate to the ominous octet: a new paradigm for the treatment of type 2 diabetes mellitus. *Diabetes*. 2009;58:773-795.

**How to cite this article:** Nah E-H, Cho S, Park H, Kim S, Kwon E, Cho H-I. The usefulness of the estimated average glucose/fasting blood glucose ratio for pancreatic β-cell function assessment in hyperglycemia during health checkups. *J Clin Lab Anal*. 2022;36:e24693. doi: 10.1002/jcla.24693