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Estimation of Diabetes Prevalence, and Evaluation of Factors Affecting Blood Glucose Levels and Use of Medications in Japan

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Abstract

Background: Diabetes is a noncommunicable disease caused by high levels of blood glucose, and it is currently one of the most important public health problems in the world. It is important to know the prevalence of diabetes, the factors affecting blood glucose levels, and the percentage of people with diabetes taking medications. Data and Methods Data and Methods: We analyzed the distribution of blood glucose levels and prevalence of diabetes using 10,917,173 observations obtained from the JMDC Claims Database in Japan. The factors that may affect blood glucose levels were analyzed by a regression model using 5,472,205 observations. Treatment with diabetes medications was analyzed with 9,932,854 and 5,466,361 observations using a method to approximate the inverse of probability by a continuous piecewise linear function. Results: The prevalence of diabetes in 2019 was estimated to be 9.63% in males and 5.33% in females ages 20 - 79; 10.78% and 7.04% for ages 20 - 89; and 10.93% and 7.65% for ages 20 - 99, respectively. In addition to age and gender, the important variables affecting blood glucose levels were *BMI*, *SBP*, *Triglyceride*, *ALT*, *AST* and *GGP*. The percentage taking medications increased up to a blood glucose level of around 175 mg/dL, but declined over that. Conclusion: The prevalence of diabetes in Japan was estimated using a very large dataset, and considering age, gender, and time trends. Some variables may be effective for controlling blood glucose levels. Nearly half of those at a serious stage of diabetes took no medications. Proper medical care for these individuals is necessary to prevent worsening diabetes and serious complications. Limitations: The dataset was observatory, and did not include those age 80 or over. Revising medical care systems to include those outside of hospitals is necessary; however, practical approaches have not yet been developed.

Keywords

Diabetes, Prevalence of Diabetes, Blood Glucose, Blood Sugar, Diabetes Medication

1. Introduction

Diabetes is a noncommunicable disease (NCD) caused by high levels of blood glucose (blood sugar). Over time, it can lead to serious heart, brain, blood vessel, eye, kidney and nerve damage [1]. Diabetes is now one of the most important public health problems in the world. The World Health Organization (WHO) [2] states that: "The number of people with diabetes rose from 108 million in 1980 to 422 million in 2014. Prevalence has been rising more rapidly in low- and middle-income countries than in high-income countries." The WHO estimates that 1.5 million deaths were directly caused by diabetes in 2019, while 2.2 million deaths were attributable to high blood glucose in 2012.

The International Diabetes Federation (IDF) [3] estimated that 463 million people worldwide (9.3% of those ages 20 - 79) were living with diabetes in 2019, and that this number would increase to 578 million by 2020, and 700 million by 2045, an increase of 51%. They also projected that 4.2 million people aged 20 - 79 would die of diabetes-related causes in 2019. Total health expenditures for diabetes were estimated at $760.3, $574.4 and $700.2 billion (US $) in 2019, 2030 and 2045, respectively. Moreover, the estimated number of people with undiagnosed diabetes was 232 million, suggesting that about half of people with diabetes were not being properly treated. Greg *et al.* [4] recently argued for setting a target to reduce the global burden of diabetes by 2030.

The US Center for Disease Control and Prevention (CDC) [5] indicated that overall prevalence of diabetes in adults aged 18 or over in the US between 2013-2016 was 13.0%; with 10.2% being diagnosed and 2.8% undiagnosed. These numbers increase as people age, with men being more likely to have the condition than women, and a significant difference exists in prevalence among races. A total of 1.5 million new cases of diabetes (6.9 per 1000 persons) were diagnosed among those aged 18 or over in 2018.

The American Diabetes Association (ADA) [6] reported that: "The total estimated cost of diagnosed diabetes in 2017 was $327 billion, including $237 billion in direct medical costs and $90 billion in reduced productivity." Diagnosing diabetes depends mainly on plasma glucose tests: the fasting plasma glucose (FPG) test; 2-h plasma glucose (2-PG) in a 75-g oral glucose tolerance test (OGTT); A1C (Hemoglobin A1c, HbA1c) test; or random (casual) plasma glucose test [7] [8].

To take the FPG test, a person cannot eat or drink anything (except water) for at least 8 h prior to testing. These tests are usually done in the morning before breakfast. A normal blood glucose level is less than 100 mg/dL (hereafter, "mg" is used for mg/dL); a level beween100 and 125 mg is diagnosed as prediabetes; and a level of 126 mg or higher as diabetes. In the OGTT, a person is diagnosed as normal if 2-PG is less than 140 mg, prediabetic if 2-PG ranges between 140 and 199 mg, and diabetic if 2-PG is 200 mg or higher. The A1C test measures average blood glucose level for the past two or three months. A person is diagnosed as normal if A1C is less than 5.7%, prediabetes for A1C between 5.7 and 6.4% and diabetes for A1C 6.5% or higher. The random plasma glucose test is a blood check at any time of the day. A person is diagnosed as diabetes if the level is 200 mg or higher.

One of the biggest problems with diabetes is that it may lead to serious complications such as heart, brain, eye, kidney, nerve, skin and foot damage over the time [9] [10]. Various studies have examined the complications of diabetes [11]-[33]. Such complications deteriorate the quality of life and productivity of patients [34] [35]. It has also been suggested that diabetes may increase the risk of cancer [36] [37] [38]. To prevent serious complications, treatment of diabetic patients should occur at the early stages of disease.

Furthermore, diabetes is considered a major risk factor for severe disease outcome with the coronavirus disease 2019 (COVID-19) [39]. Moreover, treatment of diabetes is one of the most affected NCD health services disrupted by COVID-19; that is, people with diabetes could not get necessary medical treatments due to COVID-19 [40]. Many studies on these subjects are ongoing [41]-[53].

According to the Ministry of Health, Labour and Welfare [54], medical costs for diabetes reached 1.21 trillion yen or 2.8% of Japan's total medical cost (43.4 trillion yen; 7.91% of Japanese GDP) in fiscal year 2018. There were 18.9 thousand diabetic inpatients and 224 thousand outpatients on the day the survey was held in 2017 [55]. Meanwhile, there were 7,125 deaths due to diabetes in males (11.7 per 100,000) and 5,202 in females (9.6 per 100,000) [56]. The IDF [3] estimated that there are 4.9 million people living with diabetes in Japan. The Ministry of Health, Labour and Welfare [55] reported that 14.5% of the Japanese population were strongly suspected of having diabetes (A1C 6.5% or higher or treated for diabetes). Of these, 55.6% were taking medications (including insulin injections). An additional 12.7% potentially had diabetes in 2019. However, in this survey, the sample size was only 2412, and the influence of age and other health factors were not considered. Nawata and Kimura [57] evaluated the costs and factors affecting diabetes using the 113,979 medical checkups dataset. However, they did not investigate the prevalence of diabetes (percentage with the disease).

Since diabetes is an important disease, information regarding the precise distribution of blood glucose levels, including healthy persons, is essential. It is vital that we determine the factors that affect blood glucose levels, and whether people with diabetes are receiving proper medical treatment. In this paper, we use the JMDC Claims Database to evaluate diabetes and blood glucose levels in Japan. The database contains information regarding medical payments, treatments, and observations from 13,157,681 medical checkups obtained from 3,233,271 individuals in Japan.

We first evaluate the distribution of blood glucose levels using a method based on the inverses of the probability to determine proper models. Using the obtained results and the Japanese population distribution, we estimate the prevalence of diabetes. To our knowledge, this is the first study to use a sample of this size; the results will therefore help us understand the prevalence of diabetes more precisely. We then analyze the factors affecting blood glucose levels. Finally, we evaluate use of medications to control glucose levels among diabetics in Japan. Although this study is the Japanese case, the results would help to understand diabetes in other countries.

2. Distribution of Blood Glucose Levels and Estimation of Diabetes Prevalence

In Japan, the Industrial Safety and Health Act requires most employees age 40 or older to undergo mandatory medical checkups once a year irrespective of their health condition or employer. The family members of employees can undergo medical checkups on a voluntary basis. In this paper, we use the JMDC Claims Database, which is a nationwide health claims database collecting medical information from various health insurance societies in Japan. The database contains 13,157,681 medical checkup observations obtained from 3,233,271 individuals in the sample period from January 2005 to September 2019.

To diagnose diabetes, Japan uses criteria similar to those of the ADA [58]. The differences are: the FPG test usually requires a person to abstain from eating or drinking (except water) for at least 10 h; prediabetes is diagnosed for a blood glucose level between 110 and 125 mg; and diabetes is not diagnosed by A1C level alone. We consider blood glucose level of the FPG test in this paper (hereafter, glucose level means the result of the FPG test). Figure 1 shows the distribution of blood glucose levels by gender. For the 126-mg criterion, 5.5% of 7,145,344 males and 1.75% of 3,728,977 females were diagnosed as having diabetes. If a person is taking medications to control glucose levels, the blood glucose level will be affected. Therefore, we define "diabetes" in this study as a glucose level 126 mg or higher, or taking medications to control glucose levels,

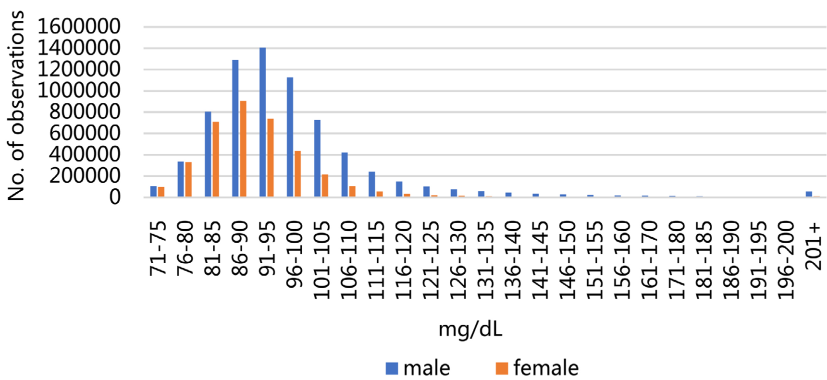

Figure 1. Distribution of blood glucose level by gender.

including insulin injections [59]-[68] (hereafter, diabetes medications). Under these criteria, 7.28% of males and 2.61% of females were diabetic. Those with a blood glucose level between 110 and 125 mg who were not taking diabetes medications were considered prediabetic. Thus, 6.41% of males and 2.70% of females were in the prediabetes stage.

The sample distributions of age and gender differed from those of the entire Japanese population. Moreover, as the sample period was over 15 years, it was necessary to consider the time trend. This required the use of models adjusting for these factors. Let P_i be the probability (hereafter, "probability" is used in theoretical frameworks and "percentage" is used in empirical results) of a person having diabetes. Figure 2 contains graphs of P_i by age and gender. P_i increases with age, and the P_i of males is higher than that of females. Here, we used the method in which the inverse function of P_i is approximated by a continuous piecewise linear function to obtain more precise models. Figure 3 shows the inverses of the probability functions calculated by $\Phi^{-1}(P_i)$ by age and gender,

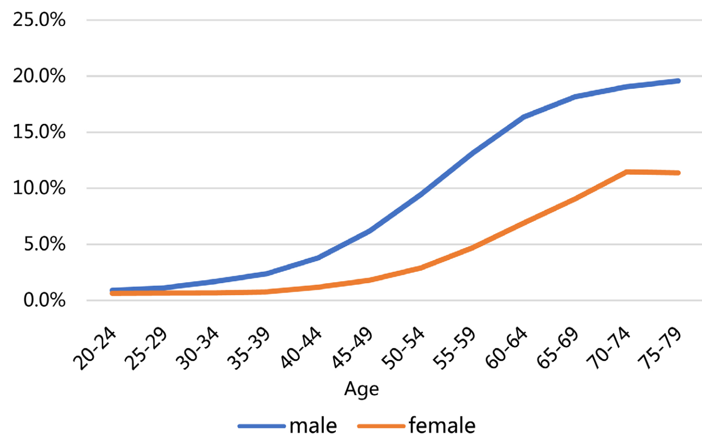

Figure 2. Probability of a person having diabetes P_i by age and gender.

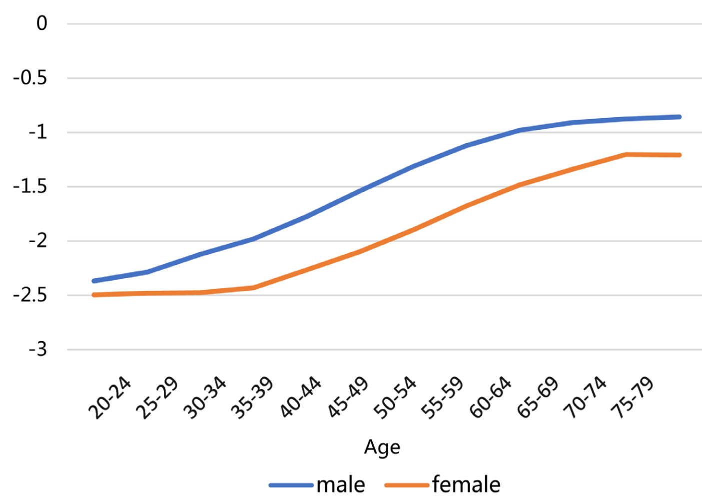

Figure 3. Inverse of probability functions of having diabetes ($=\Phi^{-1}(P_i)$) by age and gender.

where Φ is the distribution function of the standard normal distribution. If $P_i = \Phi(\alpha_1 + \alpha_2 Age)$, $\Phi^{-1}(P_i)$ becomes a linear function of age. There is a clear breakpoint around age 60 - 64 in the male graph, and two breakpoints, around age 35 - 39 and 60 - 64, in the female graph. Therefore, the graphs are approximated by continuous piecewise linear functions with one and two breakpoints. Note that the standard normal distribution is used in this study; it can be generalized to any distribution such as a logistic distribution.

Let $Diabets_{it}$ be a dummy variable taking 1 if person *i* has diabetes in year *t* and 0 otherwise. We analyze the prevalence of diabetes using the following probit models.

Model 1A (for males):

$$Y_{it} = \beta_1 + \beta_2 Age + \beta_3 Age61 + \beta_4 t1 + u_{it}, \tag{1}$$

$$P(Diabetes_{it} = 1) = P(Y_{it} > 0) = \Phi(\beta_1 + \beta_2 Age + \beta_3 Age61 + \beta_4 t1),$$

$$Age61 = (Age - 60) \cdot 1(Age \ge 61), \text{ and } t1 = Year - 2004.$$

Model 1B (for females):

$$Y_{it} = \beta_1 + \beta_2 Age + \beta_3 Age38 + \beta_4 Age65 + \beta_5 t1 + u_{it}, \tag{2}$$

$$P(Diabetes_{it} = 1) = P(Y_{it} > 0) = \Phi(\beta_1 + \beta_2 Age + \beta_3 Age38 + \beta_4 Age65 + \beta_5 t1),$$

$$Age38 = (Age - 37) \cdot 1(Age \ge 38), \text{ and } Age\_65 = (Age - 64) \cdot 1(Age \ge 65),$$

where $t1$ represents the time trend, $t1$ = year 2004 (since the sampling period started in 2005), and $1(A)$ is the indicator function that $1(A) = 1$ if A is true, and $1(A) = 0$ if A is false. Figure 4 and Figure 5 show annual numbers of observations and distributions of observations by age and gender. The breakpoints are determined so that the likelihood functions are maximized. The results of the estimation are given in Table 1, and the probability of a person having diabetes by age and gender in 2019 can be calculated from these results.

Table 1. Results of estimation: Models 1A (male) and 1B (female).

Model 1A (male)				Model 1B (female)			
Variable	Estimate	SE	t-value	Variable	Estimate	SE	t-value
Constant	−3.5139	0.0057	−612.54	Constant	−2.6234	0.0250	−104.73
Age	0.0414	0.0001	428.71	*Age*	0.0032	0.0007	4.79
*Age*61	−0.0290	0.0004	−68.40	*Age*38	0.0371	0.0008	47.89
*t*1	0.0028	0.0003	9.854	*Age*65	−0.0155	0.0011	−13.86
				*t*1	0.0046	0.0006	7.950
Log likelihood		−1,769,816		Log likelihood		−419,669.4	
No. of observations				No. of observations			
Diabetes = 0		6,644,756		Diabetes = 0		3,637,679	
Diabetes = 1		537,085		Diabetes = 1		97,653	
Total		7,181,841		Total		3,735,332	

SE: Standard Error.

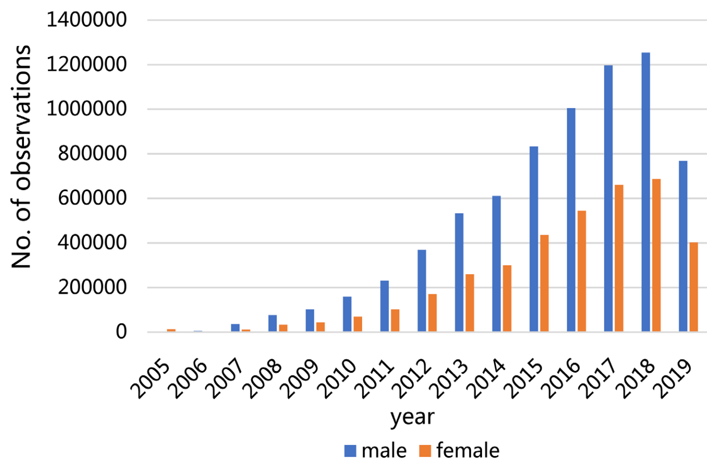

Figure 4. Annual number of observations.

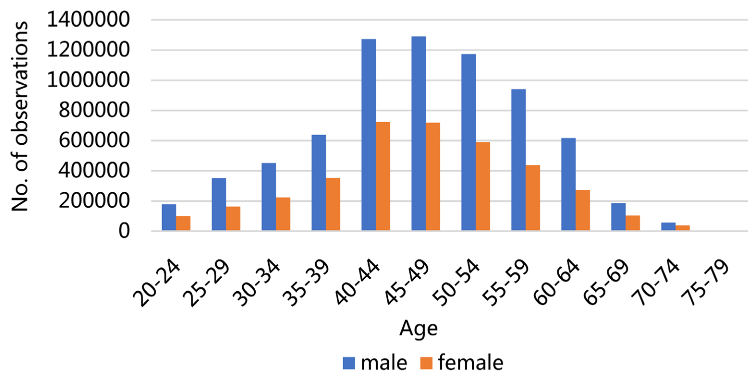

Figure 5. Distribution of observations by age and gender.

Figure 6 shows the distribution of the Japanese population by age and gender in 2019 made from the Japanese population data [69]. Combining these values, the prevalence of diabetes in 2019 can be calculated. In the age range 20 - 79, 9.63% of males and 5.33% of females had diabetes. These percentages became 10.78% and 7.04% for ages 20 - 89, and 10.93% and 7.65% for ages 20 - 99, respectively. Since the dataset does not contain persons age 80 or above, these percentages are just projections based on the models of younger generations. Therefore, estimated figures might have larger errors for elderly persons. However, the number of elderly persons will surely increase, and it is expected that the prevalence of diabetes will be a more serious problem in the future.

3. Factors Potentially Affecting Blood Glucose Levels

The results of the previous section suggested the number of people with diabetes will increase in the future. However, diabetes, especially type 2 diabetes, can be prevented by lifestyle improvements such as better eating and exercise habits. For lifestyle improvements, it is necessary to know the factors that affect blood glucose levels. In this section, the factors that might affect blood glucose levels are analyzed using a regression analysis. **Figure 7** shows the averages of blood

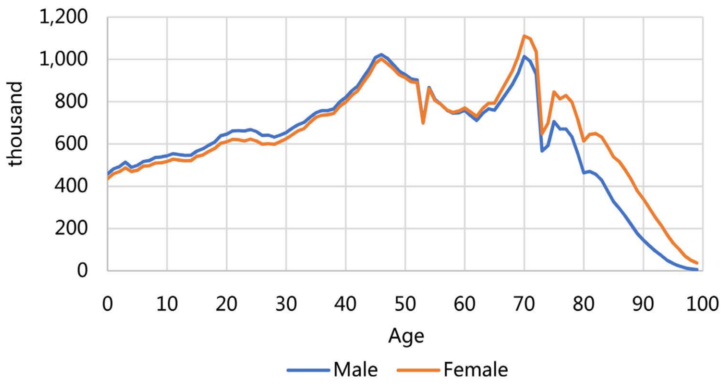

Figure 6. Distribution of Japanese population by age and gender in 2019 made from the Japanese population data [69].

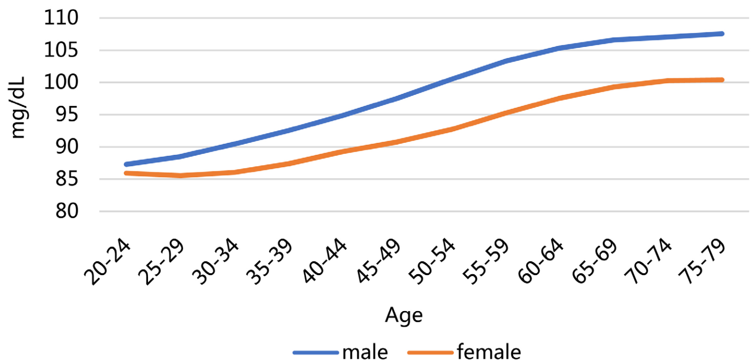

Figure 7. Average blood glucose levels by age and gender.

glucose levels by age. The average increases with age, and graphs are approximated by continuous piecewise linear functions. There is a breakpoint around age 65 - 69 in the male graph, and two breakpoints around age 35 - 39 and 65 - 69 in the female graph. Let *B_Glucose* be the glucose level, and the following model is used in the analysis.

Model 2:

$$\begin{aligned} B\_Glucose = {} & \beta_1 + \beta_2 Female + \beta_3 M\_Age + \beta_4 M\_Age69 + \beta_5 F\_Age \\ & + \beta_6 F\_Age35 + \beta_7 F\_Age70 + \beta_8 t1 + \beta_9 BMI + \beta_{10} SBP \\ & + \beta_{11} DBP + \beta_{12} HDL + \beta_{13} LDL + \beta_{14} Triglyceride + \beta_{15} ALT \\ & + \beta_{16} AST + \beta_{17} GGP + \beta_{18} Weight\_1 + \beta_{19} Weight\_20 \\ & + \beta_{20} Eat\_Fast + \beta_{21} Late\_Supper + \beta_{22} No\_Breakfast \\ & + \beta_{23} Exercise + \beta_{24} Activity + \beta_{25} Walk\_Fast \\ & + \beta_{26} Sleep + \beta_{27} Alcohol\_Freq + \beta_{28} Alcohol\_Amount \\ & + \beta_{29} Smoke + u_i \end{aligned} \tag{3}$$

$$M\_Age = 1(Male = 1)\cdot Age,\quad M\_Age69 = 1(Male = 1)\cdot(Age - 68)\cdot 1(Age \ge 69),$$

$$F\_Age = 1(Female = 1)\cdot Age,$$

$$F\_Age35 = 1(Female = 1)\cdot(Age - 34)\cdot 1(Age \ge 35),$$

and

$$F\_Age70 = \beta_4 1(Female = 1) \cdot (Age - 69) \cdot 1(Age \geq 70).$$

The definition and summary of variables are listed in Table 2. The breakpoints of ages are chosen so that R^2 of the estimated equation becomes the largest. A total of 5,472,205 observations with no missing values for any of the explanatory variables were used. The results of the estimation are presented in Table 3. Estimates of all variables except *F_Age*, *Exercise* and *Smoking* were significant at any reasonable level. *Age* is a very important factor. The blood glucose level increases as a person ages. However, the effects are different for males and females. The blood glucose level of males increases more rapidly than that of females. The blood glucose level of males increases constantly up to age 68, after which the increments become smaller. Meanwhile, the blood glucose level of females does not increase before age 35, increases from age 35 - 69, and decreases after that. Although the estimate of *Female* is positive, the effects of age are evaluated separately for males and females, and the blood glucose level of males becomes higher than that of females after age 35.

The estimate of *t*1 is positive and an increasing trend is admitted. For the variables measured at medical checkups, the estimates of *BMI*, *SBP*, *Triglycerides*, *ALT* and *GGP* were positive, while those of *DBP*, *HDL*, *LDL* and *AST* were negative. For weight changes, both estimates of *Weight*_1 and *Weight*_20 were negative. In terms of eating habits and physical condition, estimates of *Eat_Fast*, *Late_Supper*, *Activity* and *Alcohol_Amount* were positive, while those of *Speed*, *Sleep* and *Alcohol_Freq* were negative. Despite the fact that the sample size was very large, the estimates of *Exercise* and *Smoking* were not significant at the 5% level.

4. Percentage of People Taking Medications

It is quite natural that the probability of a person taking medications for diabetes would increase with blood glucose levels. Figure 8 shows the relation between blood glucose levels and the percentage of people taking medications. Since the number of observations decreases as blood glucose levels increase, the average of 5-mg blood glucose level is used in the figure to avoid the unnecessary fluctuations as the moving average method used in the time-series data analysis. (This means that 175 mg is the average of 172 - 177 mg.) The percentage increases around 175 mg as blood glucose levels increase, but then decreases. Let *Dia_Med* be a dummy variable if a person is taking diabetes medications. Figure 9 is the inverse of the probability functions. Since the graphs are very similar for males and females, we do not consider gender in this case. The graph is approximated by a continuous piecewise linear function with two breakpoints as before, and analyzed by the following probit model.

Model 3A:

$$Y_{it} = \beta_1 + \beta_2 B\_Glucose + \beta_3 B\_Glucose137 + \beta_4 B\_Glucouse173 + u_{it}, \quad (4)$$

$$P(Dia\_Med = 1) = P(Y_{it} > 0)$$
$$= \Phi(\beta_1 + \beta_2 B\_Glucose + \beta_3 B\_Glucose137 + \beta_4 B\_Glucose173),$$

Table 2. Definition and summary of variables for Model 2.

Variable	Definition	Summary	
		Average	SD
B_Glucose	Blood glucose level (FPG test), mg/dL	96.4	18.6
Age		47.9	9.73
Male	1:male; 0:female	1: 63.4%; 0: 36.6%	
Female	1:female; 0:otherwise	1: 36.6%; 0: 63.4%	
BMI	body mass index = height (m)/weight (kg)	23.0	3.7
SBP	systolic blood pressure	120.4	16.3
DBP	diastolic blood pressure	74.5	11.8
HDL	high density lipoprotein cholesterol blood, mg/dL	63.2	16.7
LDL	low-density lipoprotein cholesterol, mg/dL	121.0	31.1
Triglycerides	mg/dL	110.8	88.7
ALT	alanine aminotransferase, U/L	23.4	17.9
AST	aspartate aminotransferase, U/L	22.4	10.8
GGP	γ-glutamyl transferase, U/L	38.1	45.4
Weight_1	1: weight changed by 3 kg or more in a year; 0: otherwise	1: 27.0%; 0: 73.0%	
Weight_20	weight increased by 10 kg or more from age 20	1: 35.0%; 0: 65.0%	
Eat_Fast	1: eating faster than other people; 0: otherwise	1: 32.2%; 0: 67.8%	
Late_Supper	1: eating supper within 2 h before bedtime three times or more in a week; 0: otherwise,	1: 33.5%; 0: 66.5%	
No_Breakfast	1: not eating breakfast three times or more in a week; 0: otherwise	1: 18.4%; 0: 81.6%	
Exercise	1: doing exercise for 30 minutes or more twice or more in a week for more than a year; 0: otherwise	1: 21.3%; 0: 78.7%	
Activity	1: doing physical activities (walking or equivalent) for one hour or more daily, 0: otherwise	1: 35.0%; 0: 65.0%	
Speed	1: walking faster than other people of a similar age and the same gender; 0: otherwise	0: 44.8%; 0: 55.2%	
Sleep	1: sleeping well; 0: otherwise	1: 58.7%; 0: 41.3%	
Alcohol_Freq	0: not drinking alcoholic drinks, 1: sometimes, 2: every day	0: 41.3%; 1: 33.7%; 2: 24.9%	

Continued

Alcohol_Amount	0: not drinking; 1: drinking less than 180 ml of Japanese sake wine (with an alcohol percentage of about 15%) or equivalent alcohol in a day when drinking; 2: drinking 180 - 360 ml; 3: drinking 360 - 540 ml; 4: drinking 540 ml or more,	0: 41.3%; 1: 22.2%; 2: 22.4%; 3: 10.4%; 4: 3.7%
Smoke	1: smoking; 0: otherwise	1: 27.1%; 2: 73.9%

SD: Standard Deviation.

Table 3. Results of estimation: Model 2.

Variable	Estimate	SE	t-value
Constant	43.822	0.105	418.519
Female	16.304	0.209	78.151
M_Age	0.475	0.001	457.521
*M_Age*69	−0.438	0.021	−20.511
F_Age	0.001	0.006	0.237
*F_Age*35	0.297	0.007	42.320
*F_Age*70	−0.340	0.037	−9.182
*t*1	0.061	0.004	17.155
BMI	0.698	0.003	248.701
SBP	0.141	0.001	184.073
DBP	−0.068	0.001	−63.979
HDL	−0.014	0.001	−25.787
LDL	−0.011	0.000	−42.405
Triglycerides	0.018	0.000	176.995
ALT	0.109	0.001	143.747
AST	−0.095	0.001	−80.069
GGP	0.023	0.000	113.889
Weight_1	−0.177	0.017	−10.203
Weight_20	−0.291	0.019	−15.274
Eat_Fast	0.113	0.016	7.005
Late_Supper	0.730	0.017	43.612
No_Breakfast	0.739	0.020	36.902
Exercise	0.033	0.019	1.763
Activity	0.206	0.016	12.765
Speed	−0.436	0.015	−28.630
Sleep	−0.152	0.015	−10.080

Continued

Alcohol_Freq	−0.185	0.014	−12.805
Alcohol_Amount	0.169	0.010	17.216
Smoke	0.010	0.018	0.554
R^2	0.163		
No. of observations			

SE: Standard error.

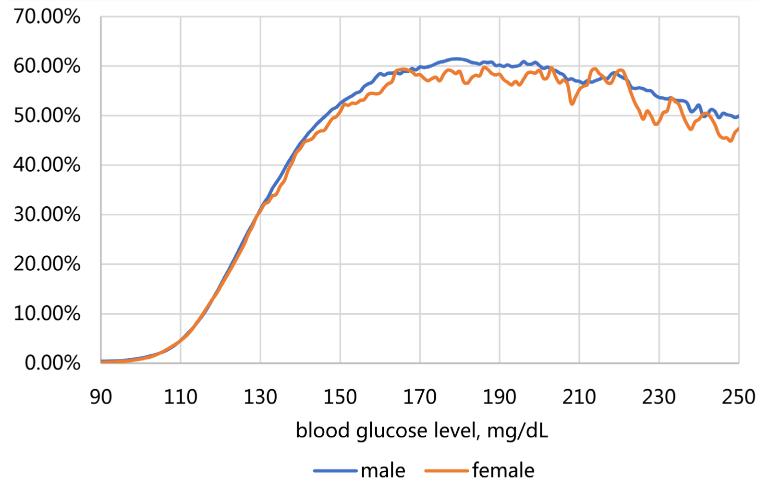

Figure 8. Probability of persons taking diabetes medications among those with diabetes by blood glucose level.

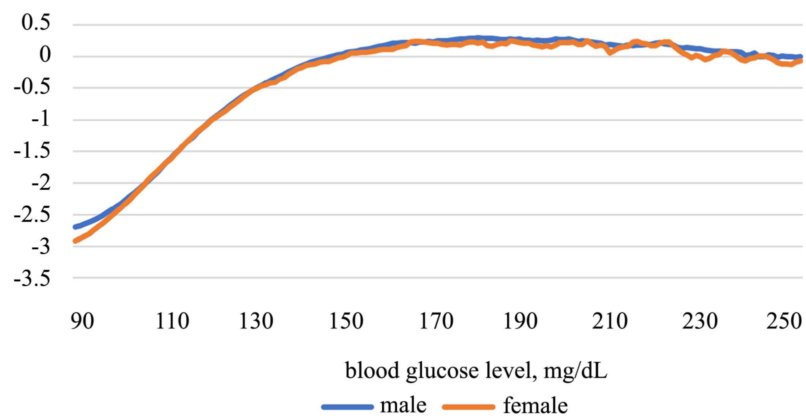

Figure 9. Inverse of probability functions given in **Figure 8**.

$$B\_Glucose137 = (B\_Glucose - 136) \cdot 1(B\_Glucose \geq 137),$$

and

$$B\_Glucose173 = (B\_Glucose - 172) \cdot 1(B\_Glucose \geq 173),$$

The breakpoints were chosen to maximize the likelihood function as before. The estimation results are given under "Model 3A" in **Table 4**.

The effect of blood glucose level on taking diabetes medications is the sum of

Table 4. Results of estimation: Models 3A and 3B.

Variable	Model 3A			Model 3B		
	Estimate	SE	t−value	Estimate	SE	t−value
Constant	−7.4826	0.0081	−923.8	−7.4826	0.0081	−923.78
B_ Glucose	0.0535	0.0001	720.9	0.0535	0.0001	720.94
*B_ Glucose*137	−0.0353	0.0002	−179.8	−0.0353	0.0002	−179.82
*B_ Glucose*173	−0.0216	0.0002	−109.0	−0.0216	0.0002	−109.02
Age				0.0275	0.0002	147.11
Female				0.0063	0.0007	8.49
t1				0.0577	0.0005	126.34
BMI				0.0015	0.0001	10.47
SBP				−0.0098	0.0002	−47.94
DBP				−0.0040	0.0001	−33.79
HDL				−0.0083	0.0001	−161.26
LDL				−0.0008	0.0000	−47.19
Triglycerides				−0.0007	0.0001	−5.36
ALT				0.0002	0.0002	1.03
AST				−0.0008	0.0000	−24.61
GGP				−0.0008	0.0000	−24.61
Weight_1				0.1225	0.0033	36.65
Weight_20				−0.0558	0.0035	−15.86
Eat_Fast				0.0525	0.0032	16.58
Late_Supper				−0.0222	0.0034	−6.57
No_Breakfast				−0.2490	0.0046	−54.30
Exercise				0.0582	0.0037	15.93
Activity				0.0093	0.0033	2.80
Speed				−0.1010	0.0031	−32.22
Sleep				−0.0148	0.0031	−4.75
Alcohol_Freq				−0.1685	0.0029	−57.17
Alcohol_Amount				0.0043	0.0019	2.21
Smoke				0.0988	0.0034	28.77
Log likelihood	−867,289			−420,503		
No. of observations	0: 959,224, 1: 340,607, total: 9,592,247			0: 5,283,301, 1: 183,060, total 5,466,361		

SE: Standard Error.

estimates of *B_Glucose*, *B_Glucose*137 and *B_Glucose*173 for the blood glucose level over 173 mg. It becomes 0.0535 − 0.0353 − 0.0216 = −0.00344 and a negative number. Its standard error becomes $\left\{\sum_i V\left(\hat{\beta}_i\right)+2\sum_{i<j} Cov\left(\hat{\beta}_i \hat{\beta}_j\right)\right\}^{0.5}$ = 0.0000741, and the t-value is −45.00. The effect is negatively significant at any reasonable significance level, admitting the probability of a person taking diabetes medications decreases if the blood glucose level is 173 mg or over. Since other health factors or characteristics of a person might affect the decision to take diabetes medications, the following equation including these factors is also estimated.

Model 3B:

$$\begin{aligned} Y_{it} = {} & \beta_1 + \beta_2 B\_Glucose + \beta_3 B\_Glucose137 + \beta_4 B\_Glucose173 + \beta_5 Age \\ & + \beta_6 t1 + \beta_7 BMI + \beta_8 SBP + \beta_9 DBP + \beta_{10} HDL + \beta_{11} LDL \\ & + \beta_{12} Triglyceride + \beta_{13} ALT + \beta_{14} AST + \beta_{15} GGP + \beta_{16} Weight\_1 \\ & + \beta_{17} Weight\_20 + \beta_{18} Eat\_Fast + \beta_{19} Late\_Supper + \beta_{20} No\_Breakfast \\ & + \beta_{21} Exercise + \beta_{22} Activity + \beta_{23} Walk\_Fast + \beta_{24} Sleep \\ & + \beta_{25} Alcohol\_Freq + \beta_{26} Alcohol\_Amount + \beta_{27} Smoke + u_i \end{aligned} \quad (5)$$

The results of the estimation are given under "Model 3B" in **Table 4**. The conclusion does not change even with this model; that is, the percentage taking diabetes medications decreases if the blood glucose level is 173 mg or over. This means that nearly half of those with serious diabetes were not taking diabetes medications despite the fact that they were in the serious diabetes stage.

5. Discussion

Age and gender are very important variables in terms of percentages of people having diabetes. We worked here with 10,917,173 observations (male: 7,181,841; female: 3,735,332) obtained from the JMDC Claims Database, a much larger dataset than has been used in previous studies. Combining the results of probit models and the Japanese population distribution by age and gender, we estimated that the percentage of people with diabetes in 2019 was 9.63% of males and 5.33% of females for ages 20 - 79, 10.78% and 7.04% for ages 20 - 89, and 10.93% and 7.65% for ages 20 - 99, respectively. We can predict that the portion of elderly persons will continue to increase, and thus the prevalence of diabetes will become more serious.

We then evaluated the effects of characteristics and health conditions in a regression model using 5,472,205 observations. As before, age and gender were very important variables, and there was an increasing trend in terms of blood glucose levels. Except for *F_Age*, *Exercise* and *Smoking*, p-values of all estimates were very small and significant at any reasonable significance level. For quantitative variables, the effect of a variable is measured by a product of its estimate and standard deviation. The values of *BMI*, *SBP*, *Triglycerides*, *ALT*, *AST* and *GGP* were 2.6 mg, 2.3 mg, 1.56 mg, 1.9 mg, −1.0 mg and 1.0 mg, respectively. This means that these variables are important to controlling blood glucose levels. The effects of all other variables including qualitative variables (dummy variables, *Alcohol_Freq* and *Alcohol_Amount*) are relatively small, less than 1 mg.

It is important to provide proper treatment and guidance regarding lifestyle to those with diabetes and prediabetes as early as possible to prevent worsening disease and more serious complications. It is quite natural that people are more likely to take diabetes medications as their blood glucose levels increase. Although the percentage of those taking diabetes medications increases with blood glucose up to 173 mg, it decreases above that. Thus, nearly half of those with very high blood glucose levels were not taking any diabetes medications. The observations of blood glucose levels 173 mg or over accounted for 0.90%. While this figure may seem small, with 5.68% of observations indicating diabetes, it is not a small portion of persons with the condition. A long length of stay (LOS) in the hospital is one of the most prominent characteristics of the Japanese treatment for diabetes [70] [71]. In 2017, the average LOS of diabetes patient was as long as 33.3 days [55]. Such long LOSs are justified only if the benefit exceeds the cost of hospitalization. Nawata and Kawabuchi [70] [71] suggested that long LOS did not produce such benefit.

These results suggest that one of the biggest problems with diabetes in Japan is that there are many people in the serious stages of the disease who are not receiving proper medical care. Proper treatment and guidance are vital to persons with diabetes and prediabetes to prevent worsening condition and other serious complications. Under the current medical payment system, methodical resources are heavily skewed towards hospitalized patients. Reallocation of medical resources will be necessary to deal with diabetes in Japan. More resources must be targeted to educating and advising patients on lifestyle modifications, as well as treating those (especially with high blood glucose levels but not currently receiving proper care) outside of hospitals. For this purpose, it will be necessary to revise the medical care system. Using internet technology to check daily health conditions to help people improve their lifestyle might be useful for the prevention of diabetes and more serious complications.

6. Conclusions

In this paper, we first estimated the percentage of people with diabetes considering age, gender, and the time trend. It was estimated that in 2019, the percentage of those with diabetes was 9.63% for males and 5.33% for females ages 20 - 79, 10.78% and 7.04% for ages 20 - 89, and 10.93% and 7.65% for ages 20 - 99, respectively. The method to approximate the inverse of probability by a continuous piecewise linear function was used to obtain more precise models.

Next, we evaluated the effects of characteristics and health conditions with a regression model. Except for *F_Age*, *Exercise*, and *Smoking*, the p-values of all estimates were very small and became significant at any reasonable significance level. Other than age and gender, the important variables for controlling blood glucose levels were: *BMI*, *SBP*, *Triglycerides*, *ALT*, *AST* and *GGP*.

Finally, we estimated the percentage of people taking diabetes medications. It is expected that the percentage would increase as blood glucose level increased.

In fact, however, the percentage increased up to 173 mg, then subsequently declined. Nearly half of those with serious diabetes did not take any diabetes medications. This indicates that there are many people not receiving medical care despite having serious diabetes. We strongly recommend taking care of these people both inside and outside of hospitals.

The dataset does not include individuals aged 80 or over. The risk of diabetes increases with age. Therefore, it is necessary to collect the data of persons aged 80 or over. Taking care of people outside of hospitals is also very important. Internet technology may provide some very useful tools. However, the proper systems and devices have not yet been developed. There are many medications for diabetes, and their evaluation is also important. These are subjects for future study.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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