Handgrip strength and diabetes in postmenopausal women: insights from the Korean National Health and Nutrition Examination Survey 2014-2019

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Abstract

Objective: This study aimed to investigate the association between handgrip strength (HGS) and diabetes mellitus (DM) in postmenopausal women in Korea relative to the menopausal duration.

Methods: Data from the Korean National Health and Nutrition Examination Survey conducted between 2014 and 2019 were analyzed. A total of 4,098 postmenopausal women aged 45 to 65 years were included in the study. Handgrip strength was measured using a digital hand dynamometer. Participants were categorized into quartiles based on HGS with Q1 representing the weakest strength and Q4 the greatest strength. The association between DM and HGS was assessed using logistic regression analysis while adjusting for relevant covariates.

Results: Postmenopausal women aged 45 to 65 years with stronger HGS were less likely to have DM ($P < 0.001$). This association persisted even after adjusting for age, body mass index, and comorbidities ($P < 0.001$). The inverse relationship between HGS and DM prevalence was more pronounced in women who had been postmenopausal for >10 years than in those who had been postmenopausal for a shorter duration (P-interaction <0.001). In addition, compared to their nondiabetic counterparts, women with DM were less likely to be categorized into the Q4 group ($P < 0.001$).

Conclusions: The findings suggest that weaker HGS was associated with likelihood of having DM among postmenopausal women in Korea. Owing to the inherent limitation to the cross-sectional study design, further research is warranted to elucidate the underlying mechanisms of the association between DM and HGS in postmenopausal women.

Key Words: Diabetes mellitus, Handgrip strength, Menopause, Sarcopenia.

(*Menopause* 2025;32:00–00)

Diabetes mellitus (DM) and its complications are an escalating global public health issue, ranking as the ninth leading cause of mortality worldwide.[1,2] Approximately one in 11 adults is affected by DM, and type 2 diabetes mellitus (T2DM) accounts for approximately 90%.[1] As the average lifespan increases and menopausal age remains stable, there is a notable increase in the proportion of postmenopausal women with DM.[3,4]

Menopause, a natural physiological process that occurs in all women, signifies the permanent cessation of menstruation due to estrogen deficiency. The onset of menopause transition coincides with a decline in the oocyte pool, which is indicative of ovarian aging.[5] This decline, which is attributed to various genetic, chromosomal, and environmental factors, may influence the development of T2DM.[6] During the menopause transition, alterations in hormone levels, particularly a decrease in estrogen production and a slower decline in androgen levels, contribute to insulin resistance, adipose tissue deposition, and a reduction in lean mass, which predisposes individuals to T2DM.[7-10]

Estrogen likely plays a role in regulating carbohydrate and lipid metabolism by promoting muscle glycogen release and stimulating lipid oxidation, which could influence skeletal muscle composition in postmenopausal women.[11] Therefore, a notable reduction in estrogen levels during menopause may contribute to a decline in muscle mass. Furthermore, estrogen levels are correlated with muscle strength and power.[12]

Handgrip strength (HGS), a straightforward measure of muscle strength and an indicator of sarcopenia, has shown promise for predicting the onset of DM and prediabetes.[13,14] Although some studies have found no association between HGS and diabetes risk,[15,16] a recent meta-analysis suggested a potential link between HGS and the likelihood of T2DM.[17] However, studies focusing on postmenopausal women are limited.

This study aimed to investigate the association between HGS and DM among postmenopausal Korean women to gain a deeper understanding of the role of muscle strength in diabetes within this specific demographic.

METHODS

Ethics statements

Ethical approval for data collection was obtained from the ethics committee of our Institutional Review Board (4-2023-1,089), and all participants provided written informed consent.

Study design, data collection, and study participants

This study used data from the Korean National Health and Nutrition Examination Survey (KNHANES) conducted between

Received April 2, 2024; revised and accepted August 8, 2024.
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Funding/support: This study was supported by a Severance Hospital Research fund for clinical excellence (C-2023-0030).

Financial disclosures/conflicts of interest: None reported.

Supplemental digital content is available for this article. Direct URL citations are provided in the HTML and PDF versions of this article on the journal's Website (www.menopause.org).
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ISSN: 1530-0374
DOI: 10.1097/GME.0000000000002453

2014 and 2019. The KNHANES is an ongoing nationwide cross-sectional surveillance program conducted annually by the Korea Centers for Disease Control and Prevention. It collects data through mobile health examination centers using three different types of surveys. First, face-to-face interviews are conducted to collect information on housing type, medical conditions, socioeconomic status, lifestyle behaviors (including smoking, drinking, and physical activity), and nutrition. Second, health condition is evaluated by measuring blood pressure, laboratory tests, dental examinations, and vision assessments. Finally, face-to-face interviews based on nutritional surveys are conducted to assess the dietary habits, supplement usage, and food hygiene. Health interviews and evaluations are conducted by trained medical staff and interviewers using standardized protocols and calibrated equipment.[18]

A total of 45,022 participants were included in the 2014-2019 KNHANES, and 8,731 women who had naturally experienced menopause underwent three HGS tests with their dominant hand. We excluded women with thyroid disease, end-stage renal disease, and any type of malignancy, or with missing information on HGS and body mass index (BMI). A total of 4,098 women, aged between 45 and 65 years, were involved in the final cohort. Information about various factors, including menopausal age, hormone use, height, weight, BMI, smoking and alcohol use, method of childbirth, history of breastfeeding, presence of comorbidities (such as hypertension, DM, impaired glucose tolerance, fasting glucose disorder, hypercholesterolemia, and hypertriglyceridemia), and exercise frequency, was gathered.

HGS measurement

HGS was measured using a digital hand dynamometer (Digital Grip Dynamometer, TKK 5401; Takei Scientific Instruments Co, Ltd, Tokyo, Japan). The participants were instructed to stand with their arms fully extended to their sides without touching their bodies. They were then asked to squeeze the dynamometer with maximum force for less than 3 seconds, which was repeated three times. A minimum rest interval of 30 seconds was provided between each trial. Absolute HGS was calculated by summing the highest reading from each hand in kilograms. Relative HGS was determined by dividing the absolute HGS with the BMI.[19,20]

DM diagnosis

DM was defined as meeting one of the following criteria: use of antidiabetic medication, fasting plasma glucose (FPG) levels exceeding 126 g/dL, or hemoglobin A1c (HbA1c) levels exceeding 6.5%. This study included women who met the aforementioned criteria or were diagnosed with DM by a doctor.

Statistical analysis

For data analysis, we categorized participants into quartiles based on their relative HGS: first quartile (0.29-0.85), second quartile (0.85-1.00), third quartile (1.00-1.15), and fourth quartile (1.15-1.89). We also performed a subgroup analysis based on duration since menopause: within 10 years and after 10 years of menopause. Furthermore, we performed a subgroup analysis based on FPG levels ≥126 g/dL or HbA1c levels ≥6.5%. To correct for items where the *P* value of each quartile in the baseline characteristic table indicated a significant difference, we set Model 1, which was adjusted for age and BMI, and Model 2, which was adjusted for age, BMI, menopausal age, hypertension, dyslipidemia, combined oral contraceptive pill, drinking, smoking, and exercising.

Data are presented as weighted mean (±standard error [SE]) for continuous variables and as weighted row percentage (±SE) for categorical variables. Categorical variables were analyzed using the χ^2 test. Analysis of variance was used to compare the baseline characteristics according to grip strength levels for confounding variables. Multivariate logistic regression was performed to evaluate the odds ratios (ORs) among the grip strength levels. An interaction analysis was performed to examine the interactions between HGS and duration (years) since menopause. SURVEYFREQ, SURVEYMEANS, SURVEYREG, and SURVEYLOGISTIC were used for statistical calculations. All statistical analyses and visualizations were performed using the R software version 4.2.1 (The R Foundation, www.R-project.org) and SAS 9.4 version (SAS Institute Inc, Cary, NC). Statistical significance was set at a two-sided *P* value of <0.05.

RESULTS

Duration since menopause

As BMI can affect HGS, the data used in this study were adjusted for BMI. A total of 4,098 women aged 45 to 65 years were stratified into four groups based on their BMI-adjusted HGS. As shown in Table 1, age and BMI were adjusted in Model 1. The basic characteristics in each quartile were different for several variables, such as menopausal age, hypertension, dyslipidemia, and exercising. These variables were adjusted in Model 2. Regardless of menopausal age, women with stronger HGS were less likely to be categorized as having DM. Among the 1,024 women who had the weakest HGS (Q1 group, Table 2), a total of 237 women were either diagnosed with DM, had an FPG level ≥126 g/dL, or had an HbA1c level ≥6.5%. In contrast, among the 1,024 women who had the strongest HGS (Q4 group, Table 2), only 82 were either diagnosed with DM, had an FPG level ≥126 g/dL, or had an HbA1c level ≥6.5% (SE, 0.98; OR, 0.31; *P* < 0.001; Table 2).

To compare the effect of cumulative postmenopausal hormonal changes on HGS and DM, women who went through menopause less than 10 years ago and women who went through menopause more than 10 years ago were examined (Supplemental Data 1, http://links.lww.com/MENO/B315, and Supplemental Data 2, http://links.lww.com/MENO/B316). In women whose menopause was within the previous 10 years, only 62 women out of 827 women with the strongest HGS (Q4 group, Table 2) were either diagnosed with DM, had an FPG level ≥126 g/dL, or had an HbA1c level ≥6.5% (SE, 1.11; OR, 0.39; *P* < 0.001; Table 2). In the Q1, Q3, and Q4 groups, as HGS increased, the prevalence of DM decreased (OR, 0.53 [*P* = 0.001]; OR, 0.39 [*P* < 0.001], respectively; Table 2). In the Q2 group, the likelihood of being diagnosed with DM, having an FPG level ≥126 g/dL, or having an HbA1c level ≥6.5% was approximately 14.07% (SE, 1.63; OR, 0.74; *P* = 0.082; Table 2).

Statistical analyses were performed for women who were menopausal for more than 10 years (Table 2). The results showed no significant differences compared to the group of women who were menopausal for less than 10 years. Because

TABLE 1. Basic participant characteristics

Variable (weighted mean ± SE)	Q1 (N = 1,024)	Q2 (N = 1,025)	Q3 (N = 1,025)	Q4 (N = 1,024)	*P* value
Age	58.06 ± 0.16	57.77 ± 0.17	57.35 ± 0.16	56.17 ± 0.17	<0.001
Menopause age	50.08 ± 0.13	50.33 ± 0.13	50.17 ± 0.13	50.03 ± 0.11	0.565
HTN	31.76 (1.64)	28.16 (1.54)	21.98 (1.43)	16.89 (1.32)	<0.001
Dyslipidemia	35.56 (1.71)	30.89 (1.76)	29.17 (1.61)	18.53 (1.33)	<0.001
Diagnosed with DM by a doctor	12.29 (1.16)	9.29 (1.15)	7.65 (0.91)	4.78 (0.77)	<0.001
FPG					<0.001
<100	57.02 (1.8)	65.77 (1.7)	67.47 (1.69)	74.27 (1.5)	
100-125	30.41 (1.62)	26.44 (1.57)	26.23 (1.59)	20.61 (1.39)	
>125	12.57 (1.17)	7.79 (0.98)	6.3 (0.85)	5.12 (0.83)	
HbA1C					<0.001
<5.8	52.15 (1.81)	57.98 (1.85)	62.54 (1.73)	68.29 (1.76)	
5.8-6.4	30.61 (1.66)	29.75 (1.69)	28.73 (1.63)	25.24 (1.6)	
>6.4	17.24 (1.28)	12.28 (1.18)	8.74 (0.95)	6.47 (0.9)	
COCP	18.19 (1.49)	18.29 (1.34)	19.52 (1.37)	17.43 (1.4)	0.763
BMI	26.51 ± 0.14	24.55 ± 0.09	23.13 ± 0.09	21.75 ± 0.07	<0.001
FPG	106.25 ± 1	101.91 ± 0.89	99.4 ± 0.58	97.86 ± 0.71	<0.001
HbA1c	6 ± 0.03	5.86 ± 0.03	5.76 ± 0.02	5.72 ± 0.03	<0.001
Drinking	4.36 (0.83)	3.97 (0.71)	3.47 (0.63)	5.13 (0.82)	0.425
Smoking	6.99 (0.9)	8.41 (1.11)	8.44 (1.03)	8.4 (1.06)	0.690
Exercise					0.001
None	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	
Once/wk	22.17 (1.41)	23.2 (1.5)	23.41 (1.55)	23.51 (1.58)	
Twice/wk	18.52 (1.45)	14.67 (1.29)	16.13 (1.36)	9.96 (0.98)	
Three times/wk	7.72 (0.97)	7.61 (0.97)	6.14 (0.85)	6.6 (0.92)	
Four times/wk	9.63 (1.09)	9.29 (1.05)	8.05 (0.92)	8.54 (0.94)	
≥ Five times/wk	41.96 (1.82)	45.22 (1.84)	46.27 (1.84)	51.39 (1.84)	

BMI, body mass index; COCP, combined oral contraceptive pill; DM, diabetes mellitus; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HTN, hypertension.

the P-interaction for duration (years) since menopause with HGS was <0.001, interactions between HGS and DM were found to be more prominent in the group of women whose menopause was more than 10 years ago.

Even though the mean age of women who were postmenopausal for ≥10 years was 61.91 ± 0.10 years and the mean age of women who were postmenopausal for <10 years was 55.84 ± 0.09 years, the aging factor was removed from the analyses by adjusting data with age (Table 2, Models 1 and 2).

Regardless of the duration of menopause, women with a strong HGS were less likely to fit the diagnostic criteria for DM (Fig. 1).

Chronological aging as covariate

Compared to the weakest HGS group (Q1), the adjusted ORs were lower in the Q4 group, regardless of age at menopause (women aged 45-65 y: OR, 0.34 [*P* < 0.001]; women whose menopause was within the last 10 years: OR, 0.42 [*P* < 0.001]; women whose menopause was over 10 years ago: OR, 0.21 [*P* < 0.001]) (Table 2, Model 1).

Multiple covariates

Multiple factors correlated with HGS, such as age, age at menopause, hypertension, dyslipidemia, combined oral contraceptive pill use, drinking, smoking, and exercise habits; hence, the covariates were adjusted and the ORs were compared. In particular, exercise in each quartile showed differences (*P* = 0.001), with a higher share of women exercising over five times a week in the Q4 group than in the Q1 group. Because exercise can strengthen HGS, this variable was adjusted. Except for the Q2 group of women whose menopause was within the last 10 years, the ORs were <1 (*P* < 0.05, P-interaction <0.001; Model 2, Table 2).

HGS of participants with DM

When analyzing the data of women with DM, those aged between 45 and 65 years, those whose menopause was within the last 10 years, and those whose menopause was over 10 years ago were less likely to be categorized into the Q4 group, which had the strongest HGS (OR, 0.36 [*P* < 0.001]; OR, 0.42 [*P* < 0.001]; OR, 0.3 [*P* < 0.001], respectively; Table 3).

HGS of participants who were not diagnosed with DM by doctor

Excluding the participants who were diagnosed with DM by a doctor, the groups were compared to assess the relationship between HGS and diabetes. When evaluating the probability of having an FPG level ≥126 g/dL or having an HbA1c

TABLE 2. OR of either being diagnosed with DM, having FPG levels ≥126 g/dL, or having HbA1c levels ≥6.5%

Variable		Total N	Event N	% (SE)	Adjusted OR[a]	*P* value	Model 1 Adjusted OR[b]	*P* value	Model 2 Adjusted OR[c]	*P* value
Grip strength of women aged 45-65 y	Q1	1,024	237	22.03 (1.47)	Ref		Ref		Ref	
	Q2	1,025	152	15.06 (1.4)	0.63 (0.48-0.82)	**<0.001**	0.64 (0.49-0.83)	0.240	0.67 (0.51-0.88)	**0.004**
	Q3	1,025	122	11.47 (1.1)	0.46 (0.35-0.6)	**<0.001**	0.48 (0.36-0.63)	0.069	0.52 (0.4-0.69)	**<0.001**
	Q4	1,024	82	7.94 (0.98)	0.31 (0.22-0.42)	**<0.001**	0.34 (0.25-0.47)	**<0.001**	0.44 (0.32-0.6)	**<0.001**
Grip strength of women who underwent menopause within the last 10 y[d]	Q1	661	127	18.07 (1.63)	Ref		Ref		Ref	
	Q2	715	95	14.07 (1.63)	0.74 (0.53-1.04)	0.082	0.74 (0.53-1.04)	0.215	0.81 (0.57-1.15)	0.247
	Q3	759	81	10.47 (1.2)	0.53 (0.38-0.74)	**0.001**	0.54 (0.39-0.75)	0.133	0.61 (0.44-0.86)	**0.004**
	Q4	827	62	7.85 (1.11)	0.39 (0.27-0.56)	**<0.001**	0.42 (0.29-0.6)	**<0.001**	0.55 (0.38-0.81)	**0.002**
Grip strength of women who underwent menopause over 10 y ago[d]	Q1	363	110	30.74 (2.65)	Ref		Ref		Ref	
	Q2	310	57	17.77 (2.65)	0.49 (0.32-0.75)	**0.001**	0.49 (0.32-0.75)	0.563	0.47 (0.31-0.73)	**<0.001**
	Q3	266	41	14.83 (2.56)	0.39 (0.25-0.62)	**<0.001**	0.39 (0.25-0.61)	0.437	0.41 (0.25-0.66)	**<0.001**
	Q4	197	20	8.38 (2.1)	0.21 (0.11-0.37)	**<0.001**	0.21 (0.11-0.37)	**<0.001**	0.22 (0.12-0.41)	**<0.001**

Bold data indicates statistically significant.

BMI, body mass index; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; OR, odds ratio; Ref, reference; SE, standard error.

[a]adjusted for BMI.

[b]Model 1: adjusted for age, BMI.

[c]Model 2: adjusted for age, BMI, menopausal age, hypertension, dyslipidemia, combined oral contraceptive pill, drinking, smoking, and exercising.

[d]P-interaction between handgrip strength and years since menopause was <0.001.

level ≥6.5% in women aged between 45 and 65 years and women who were menopausal for either less or more than 10 years, in comparison to the Q1 group, the Q4 group (women with stronger HGS) had ORs <1 ($P < 0.05$), indicating that women with strong HGS were less likely to have either an FPG level ≥126 g/dL or an HbA1c level ≥6.5% (Supplemental Data 3, http://links.lww.com/MENO/B317, and Supplemental Data 4, http://links.lww.com/MENO/B318).

DISCUSSION

This study aimed to determine whether muscle strength is associated with DM in postmenopausal women. Although the prevalence of DM in postmenopausal women is influenced by aging, it may also be increased by multiple interrelated factors. As observed in this study, postmenopausal women with high HGS were less likely to have DM.

Muscle strength is a crucial aspect for predicting health status, and HGS is one of the parameters that can measure muscle strength.[21] Although muscle mass and muscle strength are both related to glucose disposal,[22] when predicting adverse outcomes, muscle strength is a better predictor than muscle mass.[23,24] Thus, muscle strength was assessed in this study; however, as muscle strength increases with height and weight,[25,26] the values were adjusted for BMI.

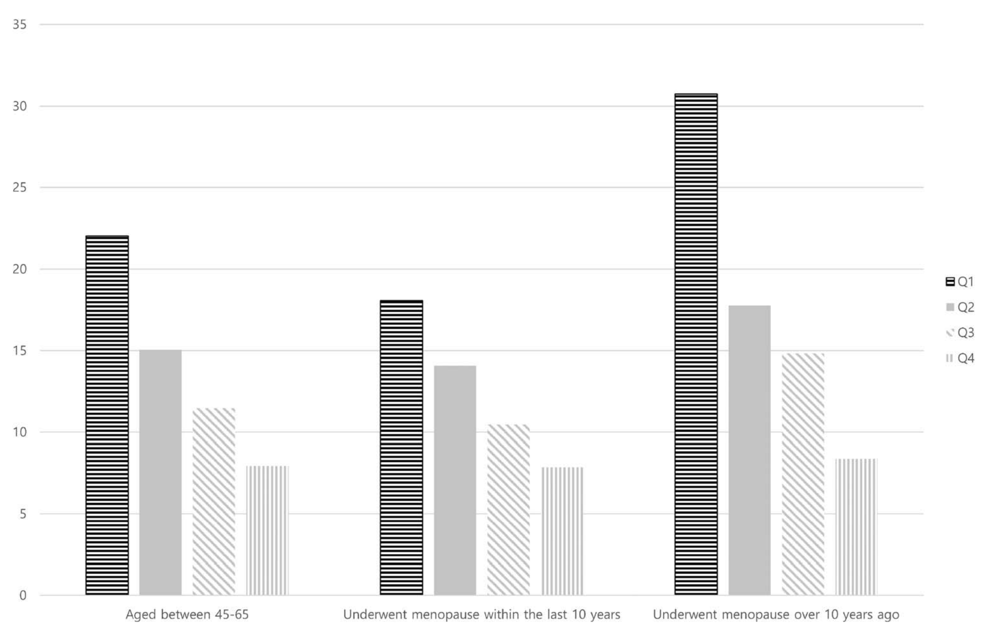

FIG. 1. Prevalence of DM, FPG levels ≥126 g/dL, or HbA1c levels ≥6.5% based on HGS (all *P* values <0.05). DM, diabetes mellitus; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HGS, handgrip strength.

TABLE 3. OR of women who were diagnosed with DM

Variable		Total N	Event N	% (SE)	OR [a]	*P* value
Grip strength of women aged 45-65 y	Q1	1,024	138	12.29 (1.16)	Ref	
	Q2	1,025	88	9.29 (1.15)	0.73 (0.53-1.02)	0.062
	Q3	1,025	85	7.65 (0.91)	0.59 (0.43-0.82)	**0.002**
	Q4	1,024	47	4.78 (0.77)	0.36 (0.24-0.54)	**<0.001**
Grip strength of women who underwent menopause within the last 10 y[b]	Q1	661	73	10.19 (1.33)	Ref	
	Q2	715	51	8.19 (1.27)	0.79 (0.51-1.21)	0.277
	Q3	759	54	6.65 (0.97)	0.63 (0.41-0.95)	0.029
	Q4	827	33	4.59 (0.86)	0.42 (0.26-0.69)	**<0.001**
Grip strength of women who underwent menopause over 10 y ago[b]	Q1	363	65	16.9 (2.1)	Ref	
	Q2	310	37	12.28 (2.5)	0.69 (0.4-1.17)	0.170
	Q3	266	31	10.99 (2.28)	0.61 (0.36-1.04)	0.068
	Q4	197	14	5.75 (1.74)	0.3 (0.15-0.61)	**<0.001**

Bold data indicates statistically significant.

DM, diabetes mellitus; OR, odds ratio; Ref, reference; SE, standard error.

[a]Adjusted for body mass index.

[b]P-interaction between handgrip strength and years since menopause was <0.001.

According to previous studies, young age at menopause and adiposity are strongly associated with increased risk of dynapenia.[27] Regarding glycemic control, skeletal muscles are not only involved in glucose metabolism but also in insulin resistance.[22] Muscle mass is a crucial factor in the regulation of glucose and energy homeostasis.[28,29] Some studies have reported that increased adipose tissue in the muscle activates the inflammatory cascade and insulin signaling pathways, resulting in insulin resistance and low muscle mass.[29,30] Given that postmenopausal women tend to have decreased muscle mass, weakened muscle strength, and increased adipose tissue due to hormonal changes, whether the increasing ratio of DM in postmenopausal women is part of the natural aging process or is independent of aging remains controversial.[31]

This study focused on postmenopausal women and the duration since menopause. Our results confirmed the general assumption of an inverse relationship between HGS and DM. Postmenopausal status is highly associated with obesity, which increases the risk of metabolism-related diseases such as DM, cardiovascular disease, venous thromboembolism, and osteoarthritis.[32] Whether HGS is weakened during aging and reflects an increased risk of having metabolic diseases or people with metabolic diseases tend to have weaker HGS is still a matter of debate.[33] In this study, when comparing the OR of HbA1c ≥6.5% or FPG levels ≥126 g/dL in women who were not diagnosed with DM by a doctor, it was found that women with stronger HGS were less likely to meet the diagnostic criteria for DM. This was more prominent in women who had menopause over 10 years ago than in women who had menopause within the last 10 years because the interaction of duration (years) since menopause with HGS was $P < 0.001$. This finding may be due to the cumulative effects of menopause, such as lower estrogen concentrations, decreased insulin secretion, increased fat mass, and increased insulin resistance.[26,34]

A previous study showed that, after the third decade of life, age and grip strength had negative correlations.[25] Decreased muscle strength with age has been reported to increase the prevalence of metabolic diseases.[34,35] In this study, after adjusting for age, some *P* values became greater than 0.05, despite being less than 0.05 before the adjustment. This might be because, for postmenopausal women, DM may be caused by more factors than chronological aging.[34] As postmenopausal women experience muscle dysfunction and degeneration owing to increased inflammatory markers, altered hormone levels, and decreased insulin sensitivity, multiple confounding factors increase the risk of DM.[26] Abdominal obesity and visceral adiposity, combined with lower muscle mass, are associated with increased fasting glucose levels and insulin resistance.[34] After consideration of the confounding factors, as shown in Model 2, women with stronger HGS (Q4 group) were less likely to fit DM diagnostic criteria.

To evaluate the HGS spectrum of people with DM, we analyzed the data of women who were already diagnosed with DM and those of women who were not. Among women with DM, regardless of duration since menopause, only a few had strong HGS. For those who were not diagnosed with DM, the HGS and DM diagnostic criteria (FPG ≥126 g/dL and HbA1c ≥6.5%) showed negative correlations. However, the women whose menopause was within the last 10 years had weaker correlations than the women whose menopause was over 10 years ago (P-interaction <0.001). This might be because the women whose menopause was over 10 years ago are not only affected by ovarian aging but also by chronological aging, wherein lower premenopausal estrogen levels during the early perimenopausal transition increase the risk of developing DM by over 47%.[31]

The current study has multiple strengths. First, because of its retrospective nature and the use of national health survey data, the study population was not biased and the results can be generalized to the Korean population. Second, because of the complex biophysical mechanisms arising during the menopause, multiple studies have excluded postmenopausal women when studying sarcopenia, dynapenia, and DM. For this reason, this study stands out in its focus on postmenopausal women. Third, this study provides valuable insights into the potential relationships between HGS and DM. However, this study also had some limitations. First, hormone therapy (HT) was not considered. Because HT data were not collected in

KNHANES starting in 2013, it was difficult to adjust HT in this study. According to previous studies, only approximately 7.8% of women aged ≥40 years were on HT in 2002 with 6.3% being on HT in Korea in 2013.[36] Because only a few women in Korea are using HT and it is still controversial whether hormone therapy has a protective effect against age-related lean body mass loss and increases muscle strength, we believe that not considering HT usage in our study did not yield misleading conclusions.[27,37] Second, both type I and T2DM were not considered in this study. As the underlying mechanisms of the two conditions are different, considering both of them might have changed the results. Third, in addition to muscle mass and strength, adiposity increases the risk of DM.[34] Further studies are required to measure visceral adiposity and determine how it affects DM and muscle strength. Fourth, because this is a cross-sectional study, it is impossible to clarify whether low HGS increases the risk of DM or DM results in low HGS. To demonstrate causal relationships between the risk of DM and weak HGS, future random controlled trials are warranted.

CONCLUSIONS

The development of DM in postmenopausal women is not only the result of chronological aging but also of complicated mechanisms involving adiposity, muscle mass, and insulin resistance. The results of this study showed that postmenopausal women with high muscle strength were less likely to have DM, and this was more obvious in women whose menopause was over 10 years ago than in women whose menopause was within the last 10 years. Owing to the limitations inherent to the nature of cross-sectional studies, further studies are warranted to clarify any causal relationships between DM and HGS. However, this study provides valuable evidence supporting an association between HGS and DM in postmenopausal women.

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