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ORIGINAL RESEARCH

# Combination of Body Mass Index and Waist Circumference Burden Determines the Risk of Atrial Fibrillation

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## ABSTRACT

**BACKGROUND** There is limited evidence regarding the significance of the combination or cumulative burden of waist circumference (WC) with body mass index (BMI) to predict future atrial fibrillation (AF) risks.

**OBJECTIVES** The authors investigated the impact of the cumulative burden of BMI and WC and their combination on the incident AF risk.

**METHODS** We included subjects 20 years of age and older who underwent 4 consecutive national health check-ups annually (between 2009 and 2013), excluding those with previous AF. The 4-year cumulative burden of BMI and WC was categorized as a burden-score, derived from the sum of the BMI and WC scores from yearly check-ups. Incident non-valvular AFs were identified using claims data from the Korean National Health Insurance Service (median 5.2 years of follow-up).

**RESULTS** A total of 3,726,172 subjects (age 44.5 ± 11.1 years, men 69.5% [n = 2,590,986 of 3,726,172]) were analyzed. Compared to a zero burden score, maximum burden score of BMI increased AF risk with an incidence rate of 1.56 of 1,000 person-years (adjusted HR: 1.32; 95% CI: 1.27-1.37). The risk of AF was markedly increased for those with the highest WC burden-score (incidence rate: 2.26/1,000 person-years; adjusted HR = 1.52; 95% CI: 1.46-1.58). Different BMI burdens within the same WC burden group did not affect the risk of AF, whereas increasing WC burden within each BMI burden group significantly elevated the AF risk. AF risk was particularly high in individuals with a moderate BMI burden with a high WC burden.

**CONCLUSIONS** The cumulative burden of WC was a more potent indicator of AF risk than either a single BMI measurement or the overall BMI burden. (JACC Asia. 2025;5:129–139) © 2025 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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**ABBREVIATIONS AND ACRONYMS**

**AF** = atrial fibrillation

**BMI** = body mass index

**IR** = incidence rate

**NHID** = Korean National Health Insurance Database

**WC** = waist circumference

Atrial fibrillation (AF) is the most prevalent persistent cardiac arrhythmia, with its global disease burden rising rapidly.[1] Obesity has been highlighted as a significant risk factor for AF,[2] and for each unit increase in body mass index (BMI), the risk of AF escalates by 3.5% to 5.3%.[3] However, assessing AF risk solely based on BMI presents challenges in clinical practice.

The predominant evidence linking obesity to AF risk derives from measurements of BMI at a single time point. This approach does not account for the cumulative effects of obesity or the risks associated with weight fluctuations.[4] Moreover, the definition of obesity based on BMI does not adequately consider central obesity or metabolic health.[5] Individuals within the normal BMI range but with a high waist circumference (WC) may still be at an elevated risk for AF.[6] Therefore, a single BMI measurement may not sufficiently represent an individual's risk of AF.

Using annual health screening data from the Korean National Health Insurance Database (NHID), we aimed to investigate the impact of a 4-year cumulative burden of both BMI and WC and their combined effects on the incidence of AF.

## METHODS

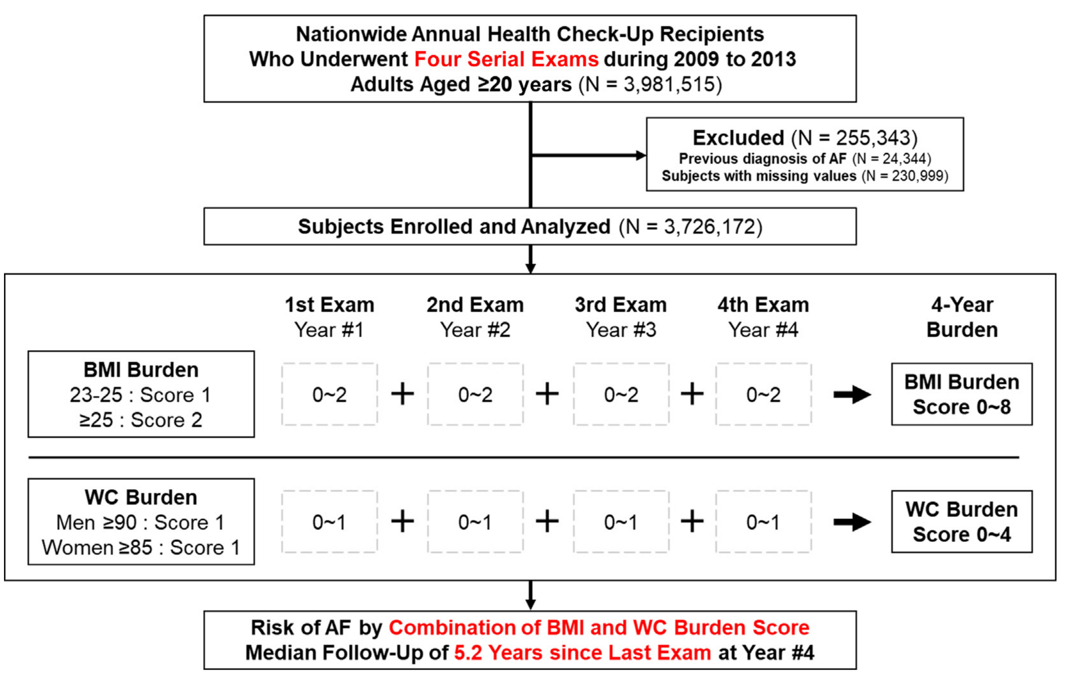
**DATA SOURCE AND STUDY POPULATION.** We used the Korean NHID which offers nationwide health screening data. The structure and features of this database have been elaborated upon elsewhere.[7] In brief, the NHID encompasses comprehensive claims-based data covering demographics, socioeconomic status, medical treatments, procedures, and disease diagnoses per the International Classification of Diseases-10th revision (ICD-10). It includes the entire Korean population, approximately 52 million people in 2019. Every insured individual in the NHID is advised to undergo general health check-ups at least every 2 years. The results of these national health screenings, which cover self-reported medical histories, lifestyle factors, anthropometric measurements, physical exams, and laboratory data, are integrated into the national health screening database, a subset of the NHID. Our study protocol aligns with the ethical guidelines of the Declaration of Helsinki. As all patient records and details were fully anonymized and de-identified before the establishment of the cohort, our study was exempted from requiring informed consent. The Institutional Review Board of Seoul National University Hospital also waived the need for approval (No. E-2008-088-1148).

**ESTABLISHMENT OF STUDY COHORT.** From the national health screening data, we initially screened 3,981,515 individuals who were 20 years of age and older who underwent at least 4 annual health check-ups consecutively between January 1, 2009, and December 31, 2013 (**Figure 1**). We excluded participants with a prior history of AF or those with missing data. Consequently, a total of 3,726,172 subjects were followed for a median duration of 5.2 years (Q1-Q3: 4.6-5.5 years). Follow-up started on the day of each participant's last (4th) health check-up exam. Participants were censored on the earliest of the following: the end of the follow-up period (December 31, 2018), the occurrence of the primary outcome, or death. We assessed the effects of single measurements of BMI and WC, burden-scores of BMI and WC, and their combined impact on the long-term risk of incident AF.

**DEFINITION OF CUMULATIVE BURDEN OF BMI AND WC.** The cumulative burden of both BMI and WC was calculated using data from 4 consecutive annual exams (Supplemental Figure 1). For BMI, scores were assigned based on the WHO obesity criteria for Asians: a score of 0 was given to an individual with a BMI $<$23 kg/m$^2$, a score of 1 for BMI between 23 and 25 kg/m$^2$, and a score of 2 for BMI $\geq$25 kg/m$^2$ for each year.[8] The 4-year burden was determined by summing the BMI scores from the 4 consecutive annual exams. The total BMI burden-score ranged from 0 to 8. As for WC, using the criteria for metabolic syndrome definition in Asians, a man with a WC $\geq$90 cm or a woman with a WC $\geq$85 cm received a score of 1 for each year.[9] The 4-year WC burden-score was determined in a manner analogous to the BMI burden-score, with the WC burden-score ranging from 0 to 4.

**DEFINITIONS OF COMPARISON GROUPS, STUDY OUTCOMES, AND COMORBIDITIES.** For comparative analyses, we divided participants into groups based on several factors: single measurements of BMI and WC at the final exam, the average BMI and WC across the 4 consecutive exams, the burden-scores of BMI and WC, and combinations of BMI and WC derived from both single measurements and burden-scores. Detailed definitions of the covariates and study outcomes are described in Supplemental Table 1. Data on age and sex were extracted from resident identification numbers. The low-income level was defined as those with the bottom 20% of household income.

**FIGURE 1** **Study Flow**




Flow of establishment of the study population and calculating the burden of body mass index (BMI) and waist circumference (WC) are shown. AF = atrial fibrillation.

The primary outcome was incident AF during the follow-up. We defined AF as participants with more than 1 episode of admission or 2 serial episodes of visiting outpatient departments with physician-assigned ICD-10 codes I48.0-I48.4 and I48.9. Comorbidities, including diabetes mellitus (DM), hypertension, dyslipidemia, chronic kidney disease, congestive heart failure, myocardial infarction (MI), and stroke, were identified using ICD-10 codes, as characterized and verified in our group's prior studies.[10-12]

**STATISTICAL ANALYSIS.** Categorical variables were represented as numbers and relative frequencies (percentages), whereas continuous variables were expressed as mean ± SD or median (Q1-Q3). Comparisons were made using the chi square test for categorical data and the independent sample Student's *t*-test for continuous data. Incidence rate (IR) for AF was determined as the number of events per 1,000 person-years. We compared the cumulative incidence of AF among groups using Kaplan-Meier censoring estimates and the log-rank test. Using both univariable and multivariable Cox proportional hazard models, we derived HRs and their 95% CIs. We computed adjusted HRs using a multivariable model that incorporated age, sex, smoking status, alcohol consumption, regular physical activity, low-income status, DM, hypertension, dyslipidemia, congestive heart failure, prior MI, previous stroke, and estimated glomerular filtration rate as covariates. All *P* values were 2-tailed; a value of <0.05 was considered statistically significant. We executed our statistical analyses with SAS version 9.4 (SAS Institute) and Stata statistical software release 17 (StataCorp).

## RESULTS

We studied a total of 3,726,172 adults (age 44.5 ± 11.1 years, 69.5% male [n = 2,590,986 of 3,726,172]) who underwent 4 consecutive nationwide annual health check-ups (Table 1). The proportion of current smokers and heavy drinkers was 31.3% (n = 1,164,657 of 3,726,172) and 8.2% (n = 306,206 of 3,726,172), respectively, and regular physical activity was reported by 22.0% (n = 820,574 of 3,726,172). Overall, the cohort's comorbid status appeared favorable,

**TABLE 1 Baseline Characteristics of the Study Population (N = 3,726,172)**

| | |
|---|---|
| Age, y | 44.5 ± 11.1 |
| Male | 2,590,986 (69.5) |
| Smoking status | |
| Nonsmoker | 1,816,677 (48.8) |
| Ex-smoker | 744,838 (20.0) |
| Current smoker | 1,164,657 (31.3) |
| Drinking habit | |
| Nondrinker | 1,489,632 (40.0) |
| Mild drinker | 1,930,334 (51.8) |
| Heavy drinker | 306,206 (8.2) |
| Regular physical activity | 820,574 (22.0) |
| Low-income status | 807,489 (21.7) |
| Comorbidities and risk factors | |
| Diabetes mellitus | 265,927 (7.1) |
| Hypertension | 768,880 (20.6) |
| Dyslipidemia | 649,765 (17.4) |
| Chronic kidney disease | 74,258 (2.0) |
| Congestive heart failure | 44,390 (1.2) |
| Previous myocardial infarction | 49,520 (1.3) |
| Previous stroke | 77,596 (2.1) |
| Health check-up results | |
| Systolic blood pressure, mm Hg | 121.5 ± 13.6 |
| Diastolic blood pressure, mm Hg | 76.4 ± 9.5 |
| Fasting glucose, mg/dL | 96.7 ± 20.7 |
| Total cholesterol, mg/dL | 194.9 ± 35.1 |
| HDL-cholesterol, mg/dL | 54.9 ± 14.8 |
| LDL-cholesterol, mg/dL | 113.8 ± 32.2 |
| Triglyceride, mg/dL | 114.3 (114.3-114.4) |
| eGFR, mL/min/1.73m$^2$ | 93.4 ± 44.6 |
| Anthropometric measurements | |
| BMI at the last exam, kg/m$^2$ | 23.8 ± 3.2 |
| WC at the last exam, cm | 80.7 ± 8.9 |
| Mean BMI of 4 exams, kg/m$^2$ | 23.7 ± 3.1 |
| Mean WC of 4 exams, cm | 80.4 ± 8.3 |

Values are mean ± SD, n (%), or median (Q1-Q3).

BMI = body mass index; eGFR = estimated glomerular filtration rate; HDL = high-density lipoprotein; LDL = low-density lipoprotein; WC = waist circumference.

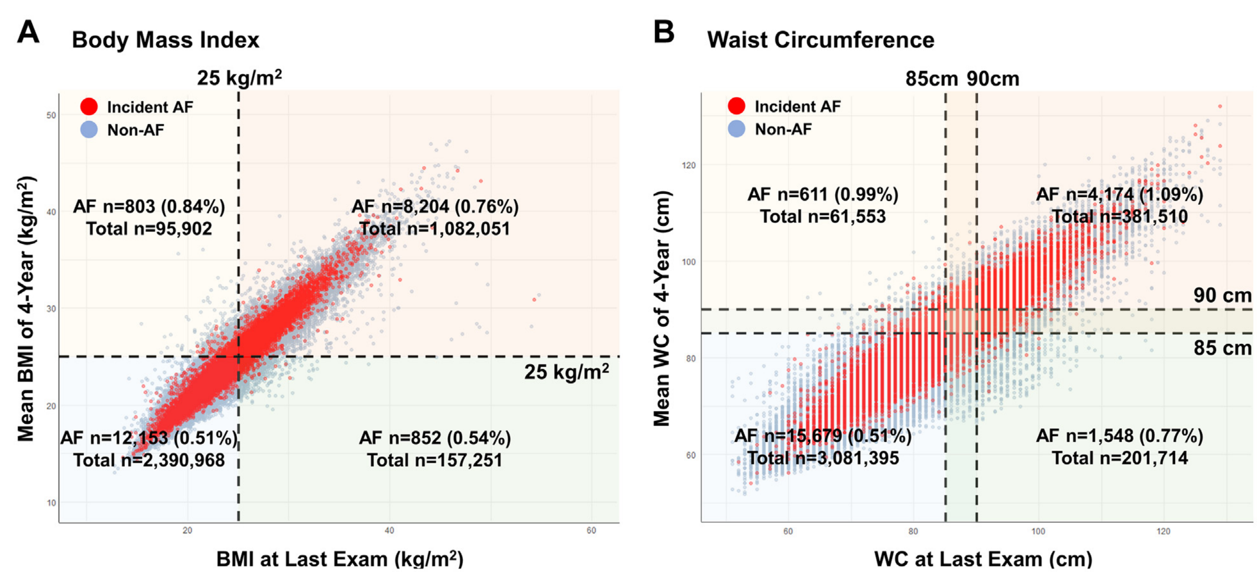
with 7.1% (n = 265,927 of 3,726,172) having DM, 20.6% (n = 768,880 of 3,726,172) with hypertension, 17.4% (n = 649,765 of 3,726,172) with dyslipidemia, and low proportions of previous history of cardiovascular diseases. The mean anthropometric measurements at the last exam were a BMI of 23.8 ± 3.2 kg/m$^2$ and a WC of 80.7 ± 8.9 cm, both slightly higher than the average values over the past 4 years (Supplemental Table 2).

**BASELINE CHARACTERISTICS ACCORDING TO BMI AND WC BURDEN-SCORES.** Baseline characteristics based on BMI and WC burden-scores can be found in Supplemental Tables 3 and 4. The number of individuals with a BMI burden score of 0 was 1,021,419, and those with a score of 8 totaled 860,731, together accounting for half of the cohort. The remaining score groups had approximately 200,000 individuals distributed evenly. Those in the higher BMI burden score groups were generally older, had a higher proportion of males, and displayed poor lifestyle habits such as higher rates of current smoking and heavy drinking and less regular physical activity. They also had a significantly higher prevalence of comorbidities and risk factors, including DM, hypertension, dyslipidemia, chronic kidney disease, congestive heart failure, previous MI, and previous stroke. The BMI at the last exam showed a notable difference between the score groups, with the score 0 group at 21.1 ± 1.1 kg/m$^2$ and the score 8 group at 28.0 ± 2.2 kg/m$^2$. A similar magnitude of difference was observed for the average BMI over the past 4 years.

For the WC burden score, the group with a score of 0 comprised 2,438,575 individuals, making up two-thirds of the cohort. Those with scores ranging from 1 to 4 had between 200,000 and 300,000 individuals. Similar to the BMI burden score groups, the higher the WC burden score, the older the age, the more male dominant the group, the worse the lifestyle factors, and the higher the prevalence of comorbidities. The group with the highest score (4), had significantly elevated proportions of risk factors, with DM at 18.0% (n = 47,335 of 262,544), hypertension at 44.8% (n = 117,708 of 262,544), and dyslipidemia at 30.8% (n = 80,911 of 262,544), even when compared to the highest BMI burden score group. The single measurement and 4-year average of WC also tended to be higher compared to BMI burden score groups, with a marked difference between the groups (score 0 at 77.0 ± 6.8 cm and score 4 at 96.2 ± 5.6 cm).

**DISCORDANCE BETWEEN SINGLE MEASUREMENT AND CUMULATIVE BURDEN OF BMI AND WC.** Figure 2 shows the discordance between the single measurements and the 4-year averages for BMI and WC. For BMI, 6.8% (n = 253,153 of 3,726,172) of the study population showed a discrepancy between the last exam and the 4-year average, whereas this was the case for 7.1% (n = 263,267 of 3,726,172) with WC. For BMI, even if individuals were classified as obese in the last exam when their 4-year average remained below 25 kg/m$^2$, their AF rate (0.54%; n = 852 of 157,251) was similar to that of the consistently non-obese group (0.51%; n = 12,153 of 2,390,968). Conversely, even if the BMI was <25 kg/m$^2$ in the last exam, when the cumulative burden fell within the obese category, the AF rate

**FIGURE 2** **Discordance Between Obesity Burden and Obesity at Single Timepoint**




The scatter plots depict the relationship between single measurement at the last exam (x-axis) and mean value of 4 serial measurements (y-axis) for (A) BMI and (B) WC. The rates and incident numbers of AF in each quadrant are shown. Abbreviations are as in Figure 1.

(0.84%; n = 803 of 95,902) was comparably high to the consistently obese group (0.76%; n = 8,204 of 1,082,051). A similar trend was observed with WC.

The results analyzing the risk of AF by combining the single measurements and the 4-year cumulative burden for both BMI and WC are presented in Table 2. Both the single measurements and cumulative burden consistently showed that an increase in WC was significantly associated with an increased risk of AF, regardless of the BMI level. The combination of cumulative burdens made a more significant prediction for elevated risk of AF due to WC increase

**TABLE 2** **Incidence and Risk of AF by BMI and WC at Single Measurement vs Cumulative Burden**

| | | Event n/Total n | IR, Per 1,000 Person-Years | Adjusted HR (95% CI) | *P* for Interaction |
|---|---|---|---|---|---|
| At last exam | | | | | |
| BMI, kg/m$^2$ | WC, cm | | | | |
| <23 | <90/85 | 6,369/1,406,419 | 0.89 | 1.00 (Ref.) | 0.258 |
| | ≥90/85 | 136/12,966 | 2.11 | 1.26 (1.06-1.49) | |
| 23-25 | <90/85 | 5,253/875,603 | 1.18 | 1.00 (Ref.) | |
| | ≥90/85 | 780/68,510 | 2.28 | 1.18 (1.10-1.28) | |
| ≥25 | <90/85 | 3,749/658,710 | 1.12 | 1.00 (Ref.) | |
| | ≥90/85 | 5,307/580,592 | 1.83 | 1.31 (1.25-1.37) | |
| From 4 serial exams | | | | | |
| Mean BMI, kg/m$^2$ | Mean WC, cm | | | | |
| <23 | <90/85 | 6,507/1,464,367 | 0.88 | 1.00 (Ref.) | 0.005 |
| | ≥90/85 | 38/1,450 | 5.38 | 1.94 (1.41-2.67) | |
| 23-25 | <90/85 | 5,672/938,976 | 1.19 | 1.00 (Ref.) | |
| | ≥90/85 | 467/26,886 | 3.50 | 1.40 (1.27-1.54) | |
| ≥25 | <90/85 | 4,230/702,673 | 1.19 | 1.00 (Ref.) | |
| | ≥90/85 | 4,777/475,280 | 2.01 | 1.31 (1.25-1.36) | |

AF = atrial fibrillation; IR = incidence rate; Ref. = reference; other abbreviations as in Table 1.

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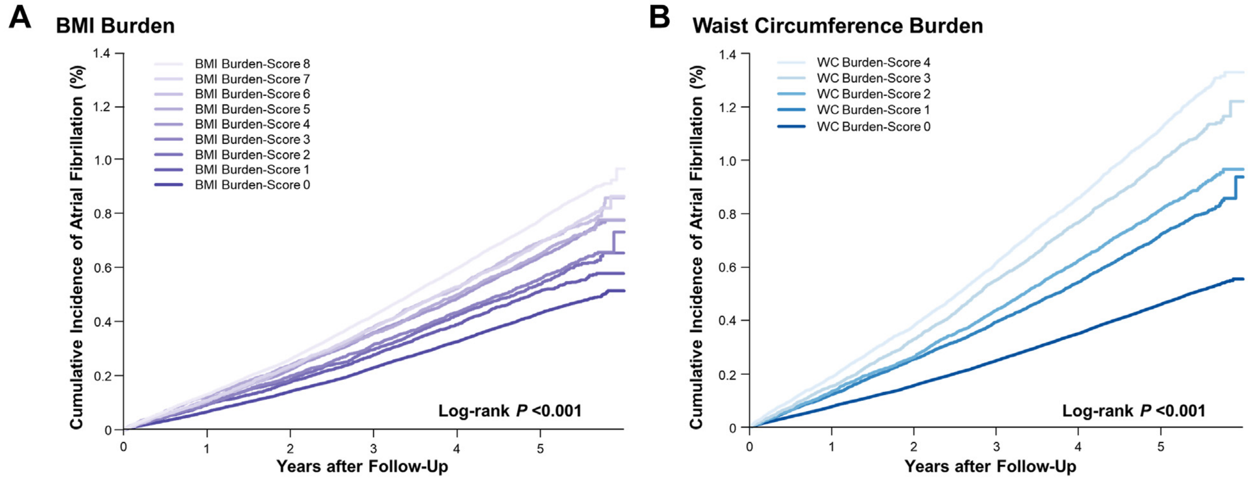
**FIGURE 3** **Cumulative Incidence of AF According to BMI and WC Burden**




| | | | | | | |
|---|---|---|---|---|---|---|
| **Burden 8** | 860731 | 859082 | 856888 | 854126 | 851126 | 588954 |
| **Burden 7** | 218048 | 217660 | 217078 | 216418 | 215667 | 145480 |
| **Burden 6** | 183083 | 182758 | 182260 | 181687 | 181104 | 121971 |
| **Burden 5** | 200851 | 200449 | 199908 | 199360 | 198729 | 135067 |
| **Burden 4** | 364644 | 363983 | 363081 | 361999 | 360936 | 256683 |
| **Burden 3** | 224337 | 223981 | 223423 | 222742 | 222064 | 150914 |
| **Burden 2** | 200915 | 200586 | 200116 | 199557 | 198939 | 134110 |
| **Burden 1** | 232568 | 232191 | 231626 | 230999 | 230356 | 153901 |
| **Burden 0** | 1021419 | 1020139 | 1017989 | 1015571 | 1012876 | 697818 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Burden 4** | 262650 | 261942 | 260951 | 259745 | 258447 | 174953 |
| **Burden 3** | 193426 | 192967 | 192269 | 191444 | 190581 | 126132 |
| **Burden 2** | 224916 | 224417 | 223765 | 222911 | 222010 | 146135 |
| **Burden 1** | 390461 | 389695 | 388596 | 387331 | 386026 | 255782 |
| **Burden 0** | 2654719 | 2651067 | 2645548 | 2639245 | 2632372 | 1825951 |

Kaplan-Meier curves for AF during follow-up according to the (A) BMI burden score and (B) WC burden score are presented. Abbreviations are as in **Figure 1**.

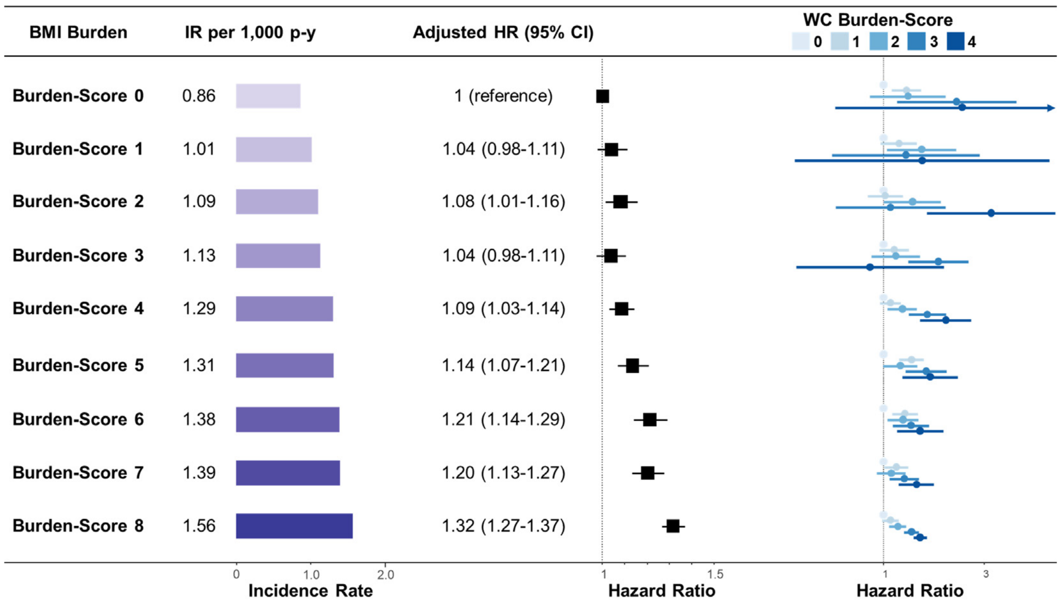
compared to the combination of single measurements ($P$ for interaction = 0.005).

**AF ACCORDING TO BMI AND WC BURDEN SCORES AND THEIR COMBINATIONS.** The IR of AF tended to increase linearly with the increase of both BMI and WC burden scores, with this trend being more prominent in WC burden (Supplemental Table 5). The IR in the group with a BMI burden score of 0 was 0.86 per 1,000 person-years, which increased to 1.56 for those with a score of 8. On the other hand, the IR of AF for a WC burden score of 0 was 0.95, which increased to 2.26 for those with a score of 4. The cumulative incidence of AF increased more markedly with WC burden score than with the BMI burden-score (**Figure 3**).

**Figure 4** presents the AF risk according to the combination of BMI and WC burden scores. The IR and adjusted risk of AF linearly increased with the BMI burden score. Within each BMI burden score group, an increasing WC burden score showed a significant additional increase in AF risk. This trend was statistically significant, not only in the low or medium BMI burden score groups but also in the group with the highest BMI burden score of 8. Within each BMI burden score group, where the WC burden score remained at 0, the IR of AF was observed to be low, ranging between 0.84 and 1.12. The increase in adjusted risk of AF with the increase of WC burden score was more pronounced in the middle-level BMI burden score of 4 (adjusted HR: 1.97; 95% CI: 1.49-2.59) than in the high-level BMI burden score groups, whereas the risk of AF also increased significantly in the group with BMI burden score of 8 (adjusted HR: 1.49; 95% CI: 1.38-1.60) (**Table 3**). However, when stratified by the WC burden score groups, the BMI burden score did not significantly affect the adjusted risk of AF (Supplemental Table 6). The results were consistent when the BMI burden score groups were simplified as 0 to 4 by the cut-off of 25 $kg/m^2$ (Supplemental Table 7).

**THE DISCRIMINATIVE ABILITY OF BMI AND WC BURDEN SCORES AND THEIR COMBINATIONS FOR PREDICTING AF.** The increase in discrimination ability for AF was evaluated (**Table 4**). The discriminative ability slightly improved with the cumulative WC burden score (area under the curve [AUC]: 0.581; 95% CI: 0.578-0.585), compared to the single measurement BMI score (AUC: 0.553; 95% CI:

**FIGURE 4** **Incident AF According to Combinations of BMI and WC Burden**




Incidence rates (IRs), adjusted HRs and 95% CIs of AF according to BMI burden scores are shown in the left and middle columns. The risks of AF by the WC burden scores within each BMI burden score group are presented in the right column. Abbreviations as in Figure 1.

0.549-0.556), single measurement WC score (AUC: 0.554; 95% CI: 0.551-0.557), their combination (AUC: 0.569; 95% CI: 0.566-0.573), or cumulative BMI burden-score (AUC: 0.569; 95% CI: 0.565-0.573). The combination of cumulative burden score of BMI and WC showed the best discriminant ability (AUC: 0.593; 95% CI: 0.589-0.597).

## DISCUSSION

In this study, we used nationwide annual health check-up data to analyze the influence of the cumulative burden and combination of 2 major anthropometric measurements, BMI and WC, on the risk of incident AF (Central Illustration). Our principal findings are as follows: 1) there was a substantial discordance between the 4-year average and single measurement for both BMI and WC; 2) a greater association with an increased risk of AF was observed with WC than BMI, and more so with the 4-year average than with the single measurement; 3) when analyzing the burden over 4 years using a scoring system, a zero WC burden consistently kept the AF risk low, regardless of the BMI burden; and 4) a high burden of WC substantially elevated the risk of AF regardless of the BMI burden, especially in middle-ranged BMI burden groups that include a population persistently overweight but not classified as obese.

Obesity is a significant and potentially modifiable risk factor for AF.[13] Increased body weight has also been related to the progression of AF.[14] The increase in adipose tissue due to obesity can impact the structure of the atria and ventricles,[15,16] cause autonomic nervous system dysfunction,[17] and impair ventricular diastolic function.[18] These adverse effects can elevate the long-term risk of AF.[13] However, there are currently some knowledge gaps concerning evidence related to AF risk based on BMI.

First, the impact of the trajectory of BMI, rather than a single measurement, is not well understood. Anthropometric measurements can exhibit significant variations over time. Fluctuations in body weight are independently associated with the occurrence of AF.[19] A high cumulative metabolic burden has also been positively correlated with the AF risk.[20] Further, maintaining long-term weight loss can reduce the risk of AF recurrence.[4] Our study has highlighted the presence of a significant discrepancy between the single measurement taken at the last exam and the measurements accumulated over 4

**TABLE 3 Incidence and Relative Risk of AF Stratified by Burden of BMI and WC**

| BMI Burden Score | WC Burden Score | Event n/Total n | IR, Per 1,000 Person Years | Unadjusted HR (95% CI) | Adjusted HR (95% CI) |
|---|---|---|---|---|---|
| 0 | 0 | 4,259/1,001,103 | 0.84 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 158/18,368 | 1.72 | 2.06 (1.76-2.42) | 1.28 (1.09-1.50) |
| | 2 | 23/1,593 | 2.91 | 3.49 (2.32-5.26) | 1.30 (0.86-1.96) |
| | 3 | 9/289 | 6.40 | 7.69 (4.00-14.77) | 2.22 (1.15-4.27) |
| | 4 | 2/66 | 6.14 | 7.36 (1.84-29.41) | 2.36 (0.59-9.42) |
| 1 | 0 | 1,036/216,059 | 0.95 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 111/14,333 | 1.55 | 1.64 (1.35-1.99) | 1.18 (0.97-1.44) |
| | 2 | 28/1,726 | 3.29 | 3.47 (2.39-5.05) | 1.51 (1.03-2.21) |
| | 3 | 6/362 | 3.41 | 3.60 (1.61-8.03) | 1.27 (0.57-2.85) |
| | 4 | 2/88 | 4.49 | 4.73 (1.18-18.94) | 1.52 (0.38-6.09) |
| 2 | 0 | 926/179,911 | 1.02 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 121/17,113 | 1.42 | 1.40 (1.16-1.69) | 1.02 (0.84-1.24) |
| | 2 | 43/2,993 | 2.90 | 2.86 (2.11-3.89) | 1.37 (1.00-1.86) |
| | 3 | 11/740 | 3.04 | 3.01 (1.66-5.45) | 1.08 (0.59-1.96) |
| | 4 | 8/158 | 10.40 | 10.28 (5.13-20.61) | 3.24 (1.61-6.51) |
| 3 | 0 | 989/192,893 | 1.01 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 187/23,516 | 1.60 | 1.58 (1.35-1.85) | 1.13 (0.96-1.32) |
| | 2 | 61/5,811 | 2.12 | 2.10 (1.62-2.72) | 1.14 (0.88-1.48) |
| | 3 | 38/1,673 | 4.61 | 4.57 (3.31-6.32) | 1.82 (1.31-2.53) |
| | 4 | 6/444 | 2.74 | 2.71 (1.22-6.05) | 0.86 (0.39-1.93) |
| 4 | 0 | 1,694/295,872 | 1.12 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 375/46,274 | 1.61 | 1.44 (1.29-1.62) | 1.08 (0.96-1.21) |
| | 2 | 172/14,759 | 2.33 | 2.09 (1.78-2.44) | 1.23 (1.05-1.44) |
| | 3 | 104/5,674 | 3.67 | 3.28 (2.69-4.00) | 1.61 (1.32-1.97) |
| | 4 | 53/2,065 | 5.16 | 4.62 (3.51-6.07) | 1.97 (1.49-2.59) |
| 5 | 0 | 722/141,513 | 1.01 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 329/37,420 | 1.76 | 1.76 (1.54-2.00) | 1.36 (1.19-1.55) |
| | 2 | 136/13,937 | 1.96 | 1.96 (1.63-2.35) | 1.20 (1.00-1.45) |
| | 3 | 93/5,767 | 3.25 | 3.24 (2.61-4.02) | 1.59 (1.27-1.98) |
| | 4 | 47/2,214 | 4.27 | 4.26 (3.17-5.73) | 1.66 (1.23-2.24) |
| 6 | 0 | 581/111,205 | 1.03 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 314/39,296 | 1.60 | 1.55 (1.36-1.78) | 1.26 (1.10-1.45) |
| | 2 | 184/19,430 | 1.90 | 1.85 (1.57-2.18) | 1.24 (1.04-1.46) |
| | 3 | 124/9,214 | 2.71 | 2.64 (2.18-3.21) | 1.35 (1.10-1.65) |
| | 4 | 73/3,938 | 3.73 | 3.63 (2.84-4.63) | 1.49 (1.16-1.91) |
| 7 | 0 | 577/108,065 | 1.05 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 355/50,278 | 1.41 | 1.34 (1.18-1.53) | 1.15 (1.01-1.31) |
| | 2 | 239/31,146 | 1.54 | 1.47 (1.26-1.71) | 1.09 (0.93-1.27) |
| | 3 | 210/19,781 | 2.14 | 2.04 (1.75-2.39) | 1.25 (1.07-1.48) |
| | 4 | 145/8,778 | 3.32 | 3.18 (2.65-3.81) | 1.43 (1.18-1.73) |
| 8 | 0 | 1,004/191,954 | 1.02 | 1.00 (Ref.) | 1.00 (Ref.) |
| | 1 | 862/140,808 | 1.21 | 1.19 (1.08-1.30) | 1.08 (0.98-1.18) |
| | 2 | 949/133,338 | 1.41 | 1.39 (1.27-1.52) | 1.17 (1.07-1.27) |
| | 3 | 1,337/149,838 | 1.78 | 1.74 (1.61-1.89) | 1.36 (1.25-1.47) |
| | 4 | 2,636/244,793 | 2.15 | 2.10 (1.96-2.26) | 1.49 (1.38-1.60) |

Abbreviations as in Tables 1 and 2.

**TABLE 4 Comparison of Discriminative Ability Among Models Predicting Incident AF**

| Model | AUC of ROC (95% CI) | *P* Value |
|---|---|---|
| 1 : BMI score (last exam) | 0.553 (0.549-0.556) | (Ref.) |
| 2 : WC score (last exam) | 0.554 (0.551-0.557) | 0.573 |
| 3 : Model 1 + model 2 | 0.569 (0.566-0.573) | <0.001 |
| 4 : BMI burden score (4-year) | 0.569 (0.565-0.573) | <0.001 |
| 5 : WC burden score (4-year) | 0.581 (0.578-0.585) | <0.001 |
| 6 : Model 4 + model 5 | 0.593 (0.589-0.597) | <0.001 |

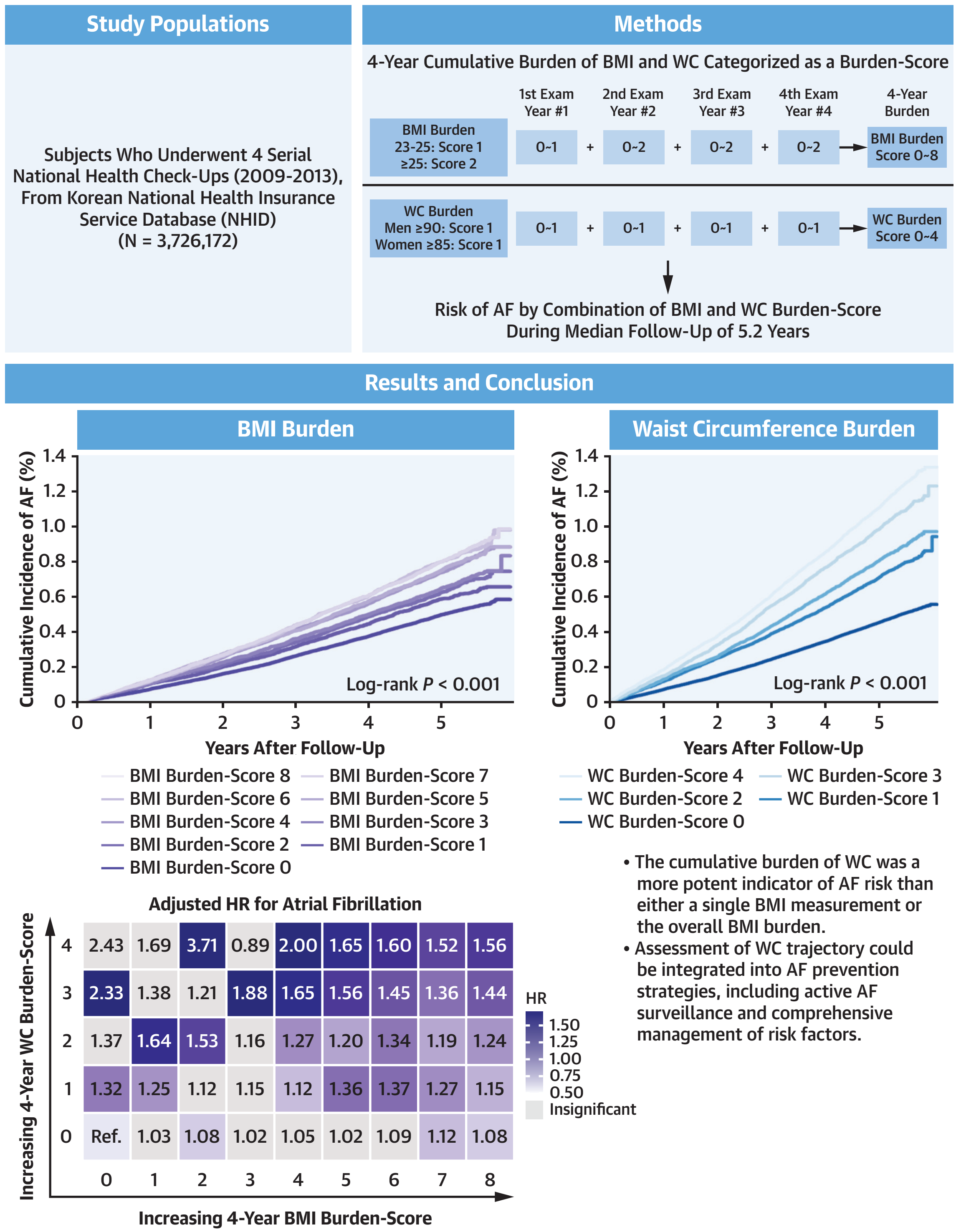
AUC = area of under the curve; ROC = receiver operating characteristic; other abbreviations as in Tables 1 and 2.

years for BMI and WC. This implies that, even if the current measurement for BMI or WC falls within the normal range, the cumulative burden of obesity or central obesity over the preceding years can still have a lingering effect. In line with this, a short-term weight gain resulting in a BMI >25 kg/m$^2$ has been associated with an increased risk of developing AF.[2] Thus, from the perspective of long-term health management, risk assessments should include both the current status and the historical, accumulated physical measurements. Tracking the trajectories of individual BMI and WC through consistent and regular health screenings may also be a pivotal strategy to discriminate long-term AF risk accurately.

Second, evaluating obesity solely based on BMI does not account for underlying metabolic health status, including central obesity. Measures such as WC and the waist-hip circumference ratio, which reflect abdominal or visceral obesity, increase the risk of AF independent of BMI.[21,22] The Asian population is known to have different obesity criteria compared to Western populations, and even at the same BMI, they typically have a higher proportion of visceral fat.[8] A recent population-based study focusing on Asians found that abdominal obesity particularly heightened the AF risk in non-obese subjects or those without comorbidities.[6] Furthermore, the higher incidence of AF in patients who are not obese (BMI <23 kg/m$^2$) but have a high WC may suggest different pathologic conditions of these subsets such as endocrine or metabolic diseases. Future research should elucidate the mechanisms by which this minority of pathologically centrally obese conditions contribute to an increased incidence of AF, differentiating the effects in this group from those with true obesity (high BMI with WC).

In our study, individuals who maintained a normal range WC for 4 consecutive years, termed 'zero WC burden," had a low AF risk level of 0.84-1.12 per 1,000 person-years. This trend was consistent even if they met the criteria for obesity based on BMI for 4 consecutive years. We observed that the middle-ranged BMI burden group with a burden score of

**CENTRAL ILLUSTRATION** Adjusted Risk of Atrial Fibrillation in Increasing Waist Circumference and Body Mass Index Burden Scores

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4 exhibited the highest future AF risk when they concurrently had a high WC burden compared to the zero WC burden group as a reference. As the BMI burden score increased, the AF risk associated with an increased WC burden appeared to be relatively attenuated. Our results underscore the clinical significance of the WC trajectories beyond the traditional "one off" BMI measurement. The cumulative burden of WC is a robust independent predictor for future AF risk, especially when compared to the single measurement of BMI. In the present study, we also found that the best discriminative abilities were demonstrated by the combination of BMI and WC burden score as well as the cumulative WC burden score, which further supports the findings mentioned above.

Our findings suggest that evaluation of the WC trajectory alongside BMI during health check-ups should be performed. The subgroup in the general population displaying the highest AF risk – those groups with high WC burden but moderate BMI burden – should be prioritized for risk factor management and lifestyle modification interventions as part of the holistic or integrated care approach to AF management[23] as recommended in guidelines.[24] Interventions to achieve a normal weight condition (as part of comprehensive lifestyle management) may significantly reduce the population-wide burden of AF.[13] In this regard, maintaining a reduced WC over a long period, thereby diminishing the cumulative burden of central obesity, might be an effective approach to mitigate population-based AF risks. Future population-based studies and clinical trials are warranted to validate our findings in various ethnic groups.

**STUDY LIMITATIONS.** First, this study is limited by its retrospective and observational nature. Second, although we presented results adjusted for potential confounders using multivariable regression analysis, the impact of unmeasured or residual confounding factors may still exist. Third, we used the ICD-10 diagnostic code to define both covariates and outcomes, which may potentially lead to misclassification bias or biases from underreporting or overreporting. In particular, we could not ascertain specific types of AF, such as paroxysmal, persistent, or permanent. Fourth, the diagnosis rate of AF may have increased due to comorbidities associated with a high WC or BMI burden score. Lastly, because the findings of this study predominantly reflect those of East Asian ancestry, their generalizability to other ethnic groups requires further validation.

## CONCLUSIONS

The cumulative burden of WC over 4 years was a more potent predictor of future AF risk than either a single BMI measurement or the overall BMI burden. Assessment of WC trajectory should be integrated into AF prevention strategies, including active AF surveillance and comprehensive management of lifestyle and risk factors.

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**CENTRAL ILLUSTRATION Continued**

The adjusted risk of atrial fibrillation (AF) based on the increase in body mass index (BMI) burden score on the x-axis and the increase in waist circumference (WC) burden score on the y-axis. The colored panels are all statistically significant ($P < 0.05$), whereas the grey-colored panels indicate statistical insignificance. Adjusted HRs and 95% CIs were calculated from multivariable Cox proportional hazards model including age, sex, smoking status, alcohol consumption, regular physical activity, low-income status, diabetes mellitus, hypertension, dyslipidemia, congestive heart failure, prior myocardial infarction, previous stroke, and estimated glomerular filtration rate as covariates.

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**KEY WORDS** atrial fibrillation, body mass index, burden, central obesity, waist circumference

**APPENDIX** For supplemental tables and a figure, please see the online version of this paper.