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Projecting the prevalence of obesity in South Korea through 2040: a microsimulation modeling approach

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1 **Title: Projecting the prevalence of obesity in South Korea through 2040: a**
2 **microsimulation modeling approach**

3
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24

ABSTRACT

Objective To project the future prevalence of obesity among populations 19 years and older by 2040 in South Korea

Design, setting, and participants Using the 'Population Health Model-Body Mass Index' (BMI) microsimulation model, the prevalence of obesity in Korean adults 19 years and over was projected until the year 2040. The model integrates individual survey data from the Korea Health Panel Survey of 2011 and 2012, population statistics based on resident registration, population projections, and complete life tables categorized by sex and age. Birth rate, life expectancy, and international migration were based on a medium growth scenario. The base population of Korean adults in 2012, devised through data aggregation, was 39,842,730. Prediction equations were formulated using BMI as the dependent variable; the individual's sex, age, smoking status, physical activity, and the preceding year's BMI were used as predictive factors.

Outcome measure BMI categorized by sex.

Results The average BMI for Korean adults in 2040 was forecast to be 23.47 kg/m² (23.91 and 23.04 kg/m² for men and women, respectively). According the Korean BMI classification, 70.05% of all adults were forecast to be 'pre-obese' (i.e., have BMIs 23 to 24.9) by 2040 (81.23% of men and 59.07% of women), followed by 25.45% who would be 'underweight or normal'.

Conclusions Public health interventions need to be established so that the current average BMI, smoking rate, and physical activity rate among Korean adults can be improved.

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3 52 **Strengths and limitations of this study**
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- 5 53 • This study is the first in South Korea to analyze individual and national data using
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7 54 microsimulation to predict the prevalence of obesity among adults.
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10 55 • We estimated the proportions of adults who will fall into various BMI categories by the
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12 56 year 2040 assuming that the average BMI, smoking rate, and physical activity rates
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14 57 measured in 2012 retain the same trend.
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17 58 • Our predictive model did not take into account nation-specific factors as applicable to
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19 59 Korea.
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79 BACKGROUND

80 The prevalence of overweight and obesity has increased markedly over the past 3 decades, and
81 concerns about health risks associated with obesity have become almost universal.[1] The increasing
82 rate of obesity is a growing public health concern not only in Western countries but also in South
83 Korea.[2] From the 1990s through the beginning of the new millennium, the prevalence of adult and
84 child obesity has increased rapidly and continues to rise steadily in parallel with rapid social and
85 economic development.[3]

86 Obesity is not only a major public health problem in and of itself, but also a factor in the
87 development of many chronic diseases; hence, it constitutes a strain on individuals and health systems
88 worldwide. In the Global Burden of Disease Study,[4] globally in 2017, a high body mass index (BMI)
89 accounted for 4.72 million deaths and 148.0 million disability-adjusted life-years. It is associated with
90 an increased risk of many disorders, including diabetes, hypertension, dyslipidemia, heart disease,
91 stroke, sleep apnea, early death, and cancer.[5-9] Moreover, obesity among older people increases the
92 risk of knee osteoarthritis[10] and reduces functional capacity and quality of life.[11-14] The
93 prevalence of these conditions rises commensurate with increased obesity, [15-18] and are associated
94 with significant morbidity, higher risks of mortality, and increased economic costs for both
95 individuals and the society at large.[19]

96 A study of data from the National Health Insurance Service in Korea found that the
97 socioeconomic cost of obesity in 2016 was approximately 9,665.32 million US dollars; medical
98 expenses accounted for 51.3% of this amount, followed by decreasing productivity (20.5%),
99 productivity loss (13.1%), early mortality (10.0%), care costs (4.3%), and transportation costs
100 (0.8%).[20] Several studies on the long-term trends of obesity prevalence in South Korea found that
101 obesity is increasing in men but not in women.[21-23] Although numerous investigators in other
102 countries have attempted to predict the prevalence of obesity into the future, only one such study by
103 Inkyung Baik was recently performed in South Korea.[2] More recent trends still need to be
104 investigated through predictive studies, and the accurate prediction of obesity prevalence remains an
105 important public health-related goal in the country.

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3 106 To efficiently establish and execute an effective healthcare policy, which would require a large budget,
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5 107 it is necessary to select future targets for policy interventions (such as high-risk groups) to predict
6
7 108 future healthcare needs and prevent budget waste.

9 109 Past prediction models incorporated a country's entire population; as such, macroscopic inferences
11 110 based on average projections for the future society were generalized. However, when establishing a
13 111 healthcare policy, it is necessary to estimate the future disease burden and medical needs of the entire
15 112 population based on future projections that reflect individual characteristics, because a real-world
17 113 understanding of the factors that are influenced by the policies or institutions is required. Individuals
19 114 are independent entities with different characteristics and needs that govern their future decisions and
21 115 behaviors. By applying these needs to the healthcare sector, health-related projections can be modeled
23 116 by reflecting health risk factors such as sex, age, life cycle activities, smoking, etc.; as such, the
25 117 effects of policy interventions can be quantified.[24] In this study, we aimed to predict the prevalence
27 118 of obesity in Korea by using microsimulation, which is optimal for considering individual properties.

30 119 Microsimulation is a modeling technique that typically uses individual microunits, each with
32 120 its own set of properties, to simulate downstream events based on the probability of transition
34 121 between predefined states and their changes over time. When used in medicine, microsimulation can
36 122 be particularly powerful because it preserves the patterns of previous behaviors and conditions, and
38 123 allows for a clearer representation and understanding of how various processes affect the total
40 124 outcome of the population over time. Collecting individual events from within a population that has
42 125 varying attributes can be used to predict and plan outcomes (such as incidence, prevalence, and cost),
44 126 and can also be used to assess the clinical and cost effectiveness of alternative health interventions.[25]
47 127 Microsimulation modeling is particularly useful for studying BMI trends because it can
49 128 simultaneously explain population dynamics such as aging, migration, and mortality. Additionally, the
51 129 longitudinal framework of these models allows for interpreting a person's change in BMI as it is
53 130 affected by factors such as a person's physical activity and behavior and thus act as a contributing
55 131 factor to other diseases, [26]

58 132 Obesity prevalence and trend estimates provide important information for research, policy,
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3 133 and intervention.[27] As mentioned above, it is necessary to estimate the magnitude of obesity
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5 134 because it has been identified as a risk factor for various chronic diseases. Because health forecasting
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7 135 predicts disease episodes and portends future events, it facilitates healthcare strategies by promoting
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9 136 the setting of goals to reduce obesity, establish health promotion interventions, and optimize resource
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11 137 allocation.[28] Obesity trends may also be used to urge governments to implement preventative
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13 138 approaches to reducing obesity.[29] Based on the above, we performed this study to project the future
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15 139 trends in obesity prevalence in South Korea up to the year 2040.
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141 **METHODS**

142 **Model**

143 We used the Population Health Model (POHEM)-BMI to estimate the prevalence of obesity in adults
144 19 years and over in South Korea from 2012 through 2040. In brief, POHEM is a time-continuous,
145 population-based, dynamic microsimulation model with individual underlying units of analysis.
146 Through dynamic simulation, POHEM creates a population and ages it, one person at a time, until
147 death.[30] The model dynamically simulates an individual's disease state, risk factors, and health
148 determinants to describe and plan health outcomes.[31] The POHEM models include cardiovascular
149 disease, various cancers, osteoarthritis, physical activity, and neurological events. The model used in
150 this study was the POHEM-BMI; the performance of each prediction step is shown in Figure 1.

151 [Insert Figure 1 here]

152 **Base population**

153 To create the base population for the POHEM-BMI model, we used the 2011- 2012 Korea Health
154 Panel survey and the resident registration-based population statistics. This constituted the base
155 population for POHEM-BMI (n=39,842,730), reflecting the Korean population. Each Korean
156 respondent 19 years of age and over (n=11,501) in 2012 was replicated using their survey-recorded
157 weights to generate a simulated cohort of approximately 39,842,730 individuals. Korea Health Panel
158 survey data are nationally representative panel surveys that incorporate health status, chronic diseases,
159 health risk behaviors, and socio-demographic characteristics. Among them, we extracted sex, age,

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3 160 current smoking status, physical activity, and the previous and current years' BMI values; these
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5 161 variables were required for the predictive equation. We then used a multiple linear regression model
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7 162 to estimate the BMI value using the independent variables age, sex, smoking status, physical activity,
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9 163 and previous BMI value as predictors. The POHEM-BMI model is auto-regressive and includes
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11 164 previous BMI values as a main explanatory variable.[26] For comparison with other international
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13 165 studies using this model, we used the variables as-is without normalizing them to Korean standards.
14
15 166 In terms of predictor definitions, a current smoker was an individual who reported smoking 'every
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17 167 day' or 'sometimes'. Practicing physical activity was defined as performing either intense physical
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19 168 activity for at least 10 continuous minutes a day, 20 minutes total per day, 3 days a week during the
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21 169 preceding week, or moderate physical activity for at least 30 minutes a day, 5 days a week during the
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23 170 preceding week.

26 171 **Simulation: Annual updates and risk transition**

28 172 The population makeup was updated by aging each person by 1 year and changing the total
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30 173 population size based on population statistics, population projections, and complete life tables
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32 174 categorized by sex and age from Statistics Korea. For population projections, we assumed a medium
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34 175 growth scenario in terms of birth rate, life expectancy, and international migration. Each person's
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36 176 BMI was updated annually by applying a predictive equation that incorporates his/her own
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38 177 characteristics. The transition probability for each stochastic characteristic was calculated based on a
39
40 178 generalized linear model.

43 179 Similar to the original POHEM-BMI, we assumed that the current individual behavioral
44
45 180 patterns persisted, and no new factors arose to prevent obesity. We also assumed that the attributes of
46
47 181 19-year-old individuals, which were entered annually, remained similar year-to-year.

49 182 **Model validation and calibration**

51 183 We established the model's validity by comparing the projected BMI average obtained from the
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53 184 prediction model to estimates obtained from the Korea Health Panel survey. We set the calibration
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55 185 cutoff point to 5% and adjusted the model by comparing the difference between the mean BMI
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57 186 estimates observed from the Korea Health Panel survey and the values derived from the prediction
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187 model categorized by sex and age. We analyzed the BMIs of each group by comparing the 2016 data
 188 available from the Korea Health Panel with the most recent data. We accepted a difference of less
 189 than 5% overall as well as in the sex- and age-categorized groups. Finally, we adjusted the
 190 demographics of the 2040 population so that the predictions were similar within a 5% margin of error.

191 **Projection**

192 The model projected the BMI of each person from 2017 to 2040. Based on demographic
 193 characteristics, the projections were then aggregated by year for each of the predefined subgroups.
 194 The various trends observed in the Korean population data were used to generate algorithms that were
 195 applied to future projections.

196 **Model outputs**

197 The final results of the BMI distributions were calculated overall and by sex. Individuals with a BMI
 198 ≥ 25 kg/m² were obese according to the Guidelines for the Management of Obesity in Korean, which
 199 is not the internationally accepted standard (see Table 1). According to this guideline, BMI is
 200 categorized into standard groupings for underweight (< 18.5 kg/m²), normal weight (18.5–22.9 kg/m²),
 201 pre-obese (23–24.9 kg/m²), obese class I (25–29.9 kg/m²), obese class II (30–34.9 kg/m²), and
 202 obese class III (≥ 35 kg/m²). All analyses in this study were performed using STATA version 13
 203 (StataCorp LLC, College Station, TX, USA).

204

205 **Table 1** BMI classification of South Korea

Classification	Body mass index (kg/m ²)
Underweight	< 18.5
Normal	18.5 – 22.9
Pre-obese	23 – 24.9
Obese class I	25 – 29.9
Obese class II	30 – 34.9
Obese class III	≥ 35

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208 **RESULTS**

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We compared the total numbers of the individuals and characteristics in the initial 2012 population to those in the projected 2040 population (see Table 2) There were 39,842,730 adults who were 19 or over in 2012 and 43,818,808 in 2040. The male:female ratio was nearly 1:1 in both 2012 and 2040. The rapid aging of the Korean population was clearly observed when comparing the 2 eras. The average age of adults was expected to increase by 10.9 years from 45.69 years in 2012 to 56.59 years in 2040 (from 44.57 to 55.54 years among men and from 46.77 to 57.63 years among women). In 2012, the proportion of young people (those in the 19–24, 25–29, 30–34, 35–39, 40–44, 45–49, and 50–54 year age groups combined) accounted for approximately 71% of the adult population (with approximately 10% in each aforementioned age group), while the proportion of individuals aged 65 years and older was relatively low at approximately 14% and that of individuals 80 years of age and older at 2.6%. However, the age group structure in South Korea 28 years later (2040) is predicted to be quite different, as the proportion of the elderly population (≥ 80 years) was estimated to be almost 12% of the total adult population, while the proportion of individuals 19–64 years (i.e., the working age population) was only 60.95% of the adult population.

There was no significant difference between the average BMIs in 2012 and 2040; however, according to the BMI classification in South Korea, approximately 50% of the adult population was ‘underweight or normal’ in 2012, whereas only 25.45% of the population was predicted to be the same in 2040. On the other hand, the ‘pre-obese’ group was expected to account for approximately 70% of the total adult population.

Table 2 Comparison of number of people, by sex and BMI classification, South Korea, 2012 and 2040

	Men		Women		Total	
<i>Population at baseline (2012)</i>						
Number of people	19,709,628		20,133,102		39,842,730	
Age (mean)	44.57		46.77		45.69	
19-24	2,094,471	(10.63)	1,873,563	(9.31)	3,968,034	(9.96)
25-29	1,748,148	(8.87)	1,642,257	(8.16)	3,390,405	(8.51)
30-34	2,047,849	(10.39)	1,962,314	(9.75)	4,010,163	(10.06)

35-39	2,095,269	(10.63)	2,027,690	(10.07)	4,122,959	(10.35)
40-44	2,316,943	(11.76)	2,248,910	(11.17)	4,565,853	(11.46)
45-49	2,120,987	(10.76)	2,026,584	(10.07)	4,147,571	(10.41)
50-54	2,160,552	(10.96)	2,128,759	(10.57)	4,289,311	(10.77)
55-59	1,616,103	(8.20)	1,631,900	(8.11)	3,248,003	(8.15)
60-64	1,145,904	(5.81)	1,194,718	(5.93)	2,340,622	(5.87)
65-69	879,627	(4.46)	997,490	(4.95)	1,877,117	(4.71)
70-74	737,954	(3.74)	954,289	(4.74)	1,692,243	(4.25)
75-79	445,317	(2.26)	707,930	(3.52)	1,153,247	(2.89)
80-	300,504	(1.52)	736,698	(3.66)	1,037,202	(2.60)
BMI (mean)	23.60		22.48		23.03	
Number of people by BMI classification						
Underweight / Normal	8,254,562	(41.88)	11,482,066	(57.03)	19,736,628	(49.54)
Pre-obese	5,264,866	(26.71)	4,207,673	(20.90)	9,472,539	(23.77)
Obese class I	5,867,369	(29.77)	4,046,607	(20.10)	9,913,976	(24.88)
Obese class II	318,297	(1.61)	324,205	(1.61)	642,502	(1.61)
Obese class III	4,534	(0.02)	72,551	(0.36)	77,085	(0.19)
Smoking status						
Smoker	8,879,037	(45.05)	450,946	(2.24)	9,329,983	(23.42)
Non-smoker	10,830,591	(54.95)	19,682,156	(97.76)	30,512,747	(76.58)
Physical activity						
Physical activity	5,199,273	(26.38)	3,103,036	(15.41)	8,302,309	(20.84)
Physical inactivity	14,510,355	(73.62)	17,030,066	(84.59)	31,540,421	(79.16)
Projected population (2040)						
Number of people	21,717,128		22,101,680		43,818,808	
Age (mean)	55.54		57.63		56.59	
19-24	1,249,921	(5.76)	1,189,386	(5.38)	2,439,307	(5.57)
25-29	1,165,520	(5.37)	1,106,562	(5.01)	2,272,082	(5.19)
30-34	1,160,786	(5.35)	1,091,788	(4.94)	2,252,574	(5.14)
35-39	1,297,513	(5.97)	1,201,131	(5.43)	2,498,644	(5.70)
40-44	1,696,199	(7.81)	1,552,548	(7.02)	3,248,747	(7.41)
45-49	1,838,461	(8.47)	1,632,766	(7.39)	3,471,227	(7.92)
50-54	1,599,077	(7.36)	1,475,843	(6.68)	3,074,920	(7.02)
55-59	1,882,322	(8.67)	1,821,485	(8.24)	3,703,807	(8.45)
60-64	1,880,827	(8.66)	1,866,992	(8.45)	3,747,819	(8.55)
65-69	2,078,232	(9.57)	2,101,456	(9.51)	4,179,688	(9.54)
70-74	1,956,454	(9.01)	2,055,954	(9.30)	4,012,408	(9.16)
75-79	1,739,807	(8.01)	1,919,444	(8.68)	3,659,251	(8.35)
80-	2,172,009	(10.00)	3,086,325	(13.96)	5,258,334	(12.00)
BMI (mean)	23.91		23.04		23.47	
Number of people by BMI classification						
Underweight / Normal	2,327,521	(10.72)	8,823,981	(39.92)	11,151,502	(25.45)

	Pre-obese	17,641,668	(81.23)	13,055,482	(59.07)	30,697,150	(70.05)
I	Obese class	1,712,332	(7.88)	221,829	(1.00)	1,934,161	(4.41)
II	Obese class	33,455	(0.15)	388	(0.00)	33,843	(0.08)
III	Obese class	2,152	(0.01)	0	(0.00)	2,152	(0.00)

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The model was well calibrated in both the initial population and from 2017 to 2040.

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Differences in each of the variables estimated between 2013 to 2016, which were derived from the

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Korea Health Panel data, were within the 5% range only when using the predictive model.

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Additionally, when compared to the population structure for 2040 (the final year) as predicted by

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Statistics Korea, the total population and gender and age-specific ratio were similar.

236

Figure 2 shows the average predicted BMIs between 2017 and 2040. Each average BMI

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value from 2013 to 2016 was estimated from the Korea Health Panel survey. The average BMI for the

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entire adult population is predicted to increase very slightly from 23.19 kg/m² in 2017 to 23.46 kg/m²

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in 2036 and is expected to remain steady thereafter. The predicted mean BMI trends are similar for

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men and women; the mean BMI in adult men was projected to increase only slightly, from 23.72

241

kg/m² in 2017 to 23.91 kg/m² in 2036 (from 22.67 kg/m² in 2017 to 23.01 in 2036 kg/m² for adult

242

women) and then almost plateau thereafter.

243

[Insert Figure 2 here]

244

The BMI distributions for men and women from 2012 to 2040 are shown in Figure 3. The

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proportions of 'pre-obese' individuals in both sexes are predicted to increase dramatically over time,

246

while the proportions of individuals who are classified as 'underweight or normal' and 'obese' will

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gradually decrease. As of 2025, 52.35% of all male adults were expected to be pre-obese, with that

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proportion expected to be close to 81.23% by 2040. Moreover, 53.24% of all adult women are

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expected to be 'pre-obese' by 2035, with the proportion rising to almost 59.078% by 2040.

250

[Insert Figure 3A and 3B here]

251

252 DISCUSSION

253 The purpose of this study was to predict the prevalence of obesity in South Korea in the year
254 2040 using a microsimulation model. In the field of healthcare, microsimulation can predict the
255 burden of disease by modeling various health risk factors that occur during an individual's lifetime.
256 Given macro-effects such as changes in population structures in the forecasting model,
257 microsimulation is very useful in that it can estimate both disease burdens and medical needs across
258 the country.[24] While microsimulation models have been steadily evolving across health- and
259 economy-related fields in many European countries,[32] they have yet to be actively utilized in South
260 Korea (especially for healthcare). In this study, we strove to predict future adult obesity rates in South
261 Korea using the POHEM-BMI, which is developed by Statistics Canada. POHEM is one of several
262 population-based health dynamic microsimulation models used worldwide. Dynamic microsimulation,
263 in the context of social science and population health, is a simulation of individuals (i.e., micro-level)
264 and their behaviors, statuses, and actions (dynamics) over time.[33] These are modeled as desired
265 using multiple sources of empirical data, including cross-sectional surveys, administrative databases,
266 vital statistics, and census data.[31]

267 Summarizing the predicted results, the average BMI of South Korea's adult population aged
268 19 years and older was expected to be 23.47 in 2040, while the percentage of 'pre-obese' individuals
269 was expected to increase over time. While it is encouraging that the proportion of 'obese' people (i.e.,
270 those with BMIs ≥ 25 kg/m²) in 2040 is predicted to be much lower than that in 2012, it is
271 discouraging that the proportion of 'underweight or normal' individuals is also markedly lower. Most
272 notably, the pre-obesity rate is predicted to rise dramatically. In addition to the sex and age of each
273 individual, our model includes only smoking and physical activity as health-related behaviors. The
274 distributions of these factors were assumed to remain equal across the years; hence, our data show that
275 maintaining smoking and physical activity rates at 2012 levels among adults will lead to a sharp
276 increase in the 'pre-obese' population by 2040.

277 To our knowledge, the only other study that predicted future obesity rates among South
278 Korean adults was the aforementioned investigation by Baik.[2] That study explored factors affecting

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3 279 adult obesity as well as abdominal obesity, and constructed forecasting models to predict obesity
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5 280 prevalence rates in 2020 and 2030 using the Korea National Health and Nutritional Examination
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7 281 Survey (KNHANES). The prevalence rates of obesity among men and women in that study were
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9 282 predicted to be 47% and 32%, respectively, in 2020 and 62% and 37%, respectively, in 2030; these
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11 283 data were inconsistent with our own. The differences appeared to be caused by the different secondary
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13 284 sources used in the 2 studies, as well as the different independent variables and prediction
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15 285 methodologies. In particular, the obesity rate in the initial population according to the KNHANES
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17 286 tended to be higher; as such, a higher initial prevalence rate would lead to a higher projection.[34]
18
19 287 Most importantly, Baik's study did not consider the preceding year's BMI, which was a major
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21 288 independent variable in our study; this may be a major explanation for the differences in findings
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23 289 between the 2 studies. We also compared our results to those predicted in Canada using the same
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25 290 model we used; based on self-reported BMIs, approximately 59% of the adult Canadian population
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27 291 was predicted to be 'overweight or obese' (i.e., BMIs >25 kg/m²) by 2030, which is a much higher
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29 292 percentage than that predicted in South Korea (10.12%).
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33 293 With respect to worldwide comparisons, whether cutoff points for overweight and obesity
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35 294 should be lower for Asians than for another ethnic group remains debated.[35] Because of racial
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37 295 differences, the World Health Organization has proposed regarding BMIs of 18.5–22.9 kg/m² as
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39 296 optimal, 23–24.9 kg/m² as overweight, 25–29.9 kg/m² as moderate obesity, and ≥30 kg/m² as severe
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41 297 obesity for Asians.[36] If the international BMI standard were to be applied in our study, the results
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43 298 would be much more favorable given that a large proportion of subjects would be classified as normal.
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45 299 However, more research is needed to determine particular BMI values that increase the likelihood of
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47 300 developing particular chronic disease, depending on the sex and age of the individual. The Korean
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49 301 Society of Obesity, which was established to improve obesity management through research and
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51 302 education, revised its clinical practical guidelines for the prevention and treatment of obesity in 2018.
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53 303 The new guidelines renamed the "overweight" category to "pre-obese", and divided obesity into 3
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55 304 categories, thereby aiming to highlight the risk of obesity instead of promoting the term "overweight."
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57 305 The most recent guidance is based in part on data from of 84,690,131 Korean adults extracted from
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3 306 the Korean National Health Insurance Service Health Checkup Database between 2006 and 2015. By
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5 307 including the entire population registered in the National Health Insurance Services Database, they
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7 308 calculated the first and second cutoff points corresponding to the increased risk of any of 3
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9 309 accompanying diseases (type 2 diabetes, hypertension, and dyslipidemia). The first and second BMI
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11 310 cutoff levels were 23 kg/m² and 25 kg/m², respectively.[37,38] Rather than emphasizing the BMI
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13 311 classification criteria, however, future studies ought to analyze the BMI reference points that can
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15 312 significantly predict the occurrence of chronic diseases by sex and age group. Based on such evidence,
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17 313 the developing governmental 'National Health Promotion Comprehensive Plan' needs to incorporate
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19 314 additional, wider-ranging goals that take into account the characteristics of each sex and age group,
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21 315 rather than presenting goals for obesity prevalence among adult men and women. Moreover,
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23 316 systematic public health interventions that are tailored to individual characteristics need to be
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25 317 established.

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28 318 A limitation of this study was that the forecast model was not specific to Korea, as no
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30 319 microsimulation model for predicting obesity prevalence has been developed in this country.
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32 320 Therefore, we borrowed a model from Statistics Canada and performed an international comparison.
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34 321 For that reason, the variables used as predictors included only sex, age, smoking, physical activity,
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36 322 and the preceding year's BMI value. Nevertheless, our study's importance is that it is the first to
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38 323 examine the possibility of using microsimulation to predict future BMI averages in South Korea.
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40 324 Additionally, it is important to note that the BMI of the future adult population was predicted after
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42 325 considering the change in population structure at the macro level as well as individual health behavior
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44 326 components at the micro level.

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48 49 328 **CONCLUSION**

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51 329 The key finding of this study is that by 2040, 70.05% of Korean adults are predicted to be
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53 330 pre-obese. Utilizing data sources available in Korea, the possibility of applying and expanding on the
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55 331 concept of microsimulation was explored. In future studies, a model suitable for South Korea needs to
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57 332 be developed, and the effectiveness of specific health policies ought to be assessed by applying
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333 various relevant scenarios to the basic forecasting model.

334

335 **Abbreviations**

336 BMI: body mass index; KNHANES: Korea National Health and Nutritional Examination
337 Survey, POHEM: Population Health Model

338 **Contributions**

339 YS (the first author) designed the study, analyzed and interpreted the data, and wrote the
340 paper. YE participated in the statistical analysis. DS provided assistance in the interpretation of the
341 data and preparation of the manuscript. SJ (the corresponding author) directed this study. All authors
342 read and approved the final version of the manuscript.

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347 the manuscript.

348 **Competing Interests**

349 The authors declare that they have no competing interests.

350 **Ethics approval**

351 This study used publicly available data of Korea Health Panel Survey 2011-2012 from The
352 Korea Institute for Health and Social Affairs and the National Health Insurance, population statistics
353 based on resident registration, population projections, complete life tables and future mortality rates
354 from Statistics Korea. The dataset does not contain any identifiable personal information. Ethical
355 approval was given by the Institutional Review Board of Korea University, Seoul, Korea (IRB No.
356 KUIRB-2020-0018-01).

357 **Provenance and peer review** Not commissioned; externally peer reviewed.

358 **Data sharing statement**

359 The Korea Health Panel Survey data used in this article is available in

360 <https://www.khp.re.kr:444/eng/data/data.do>. Detailed information on the survey design and data
361 characteristics are provided at <https://www.khp.re.kr:444/eng/survey/sampling.do>. Population
362 statistics, population projections, and complete life tables are available from <http://kosis.kr/eng/>.

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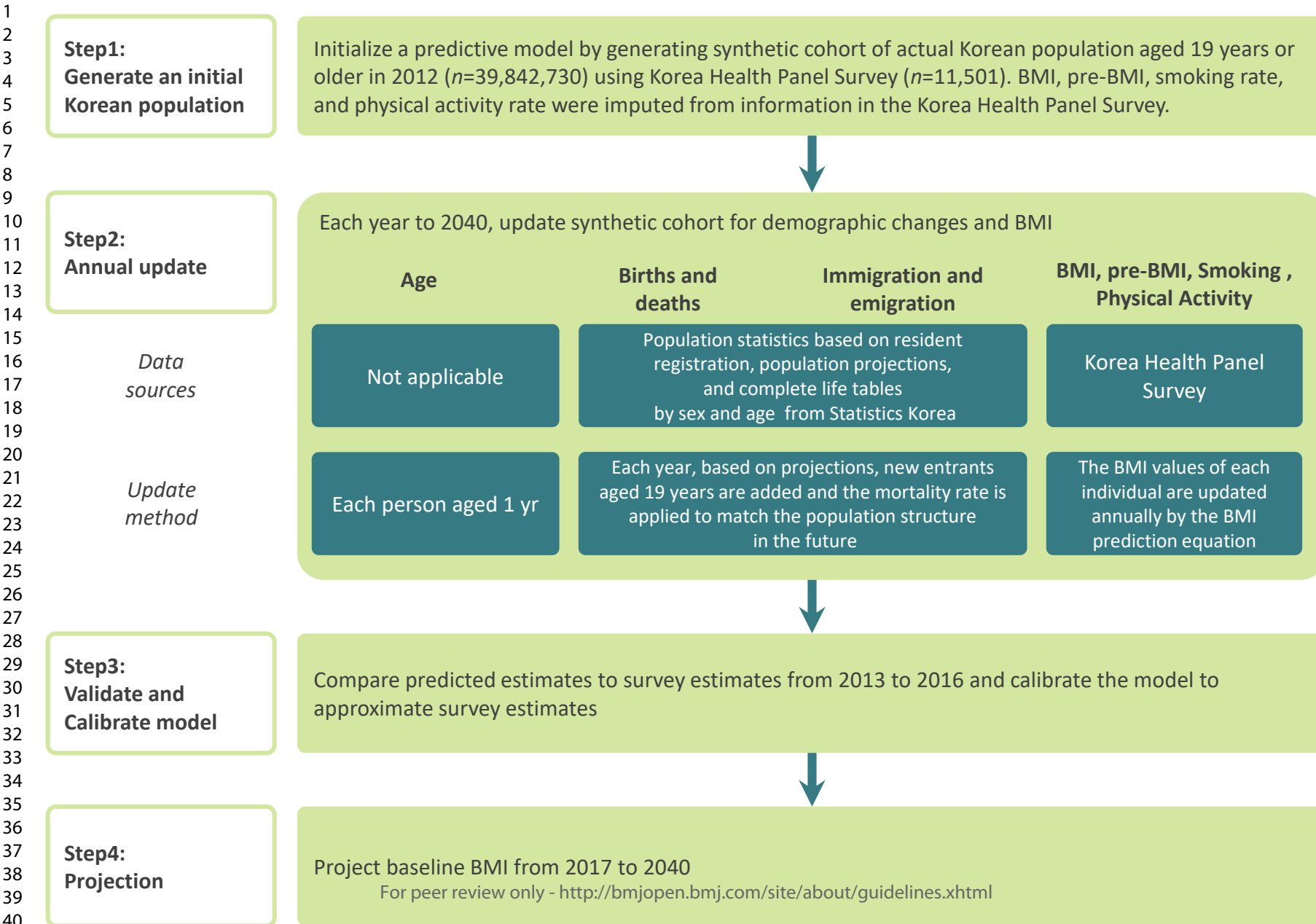
Figure 1 Summary of data sources and methods used to generate and validate projections of distribution of BMI categories in South Korea, 2012-2040

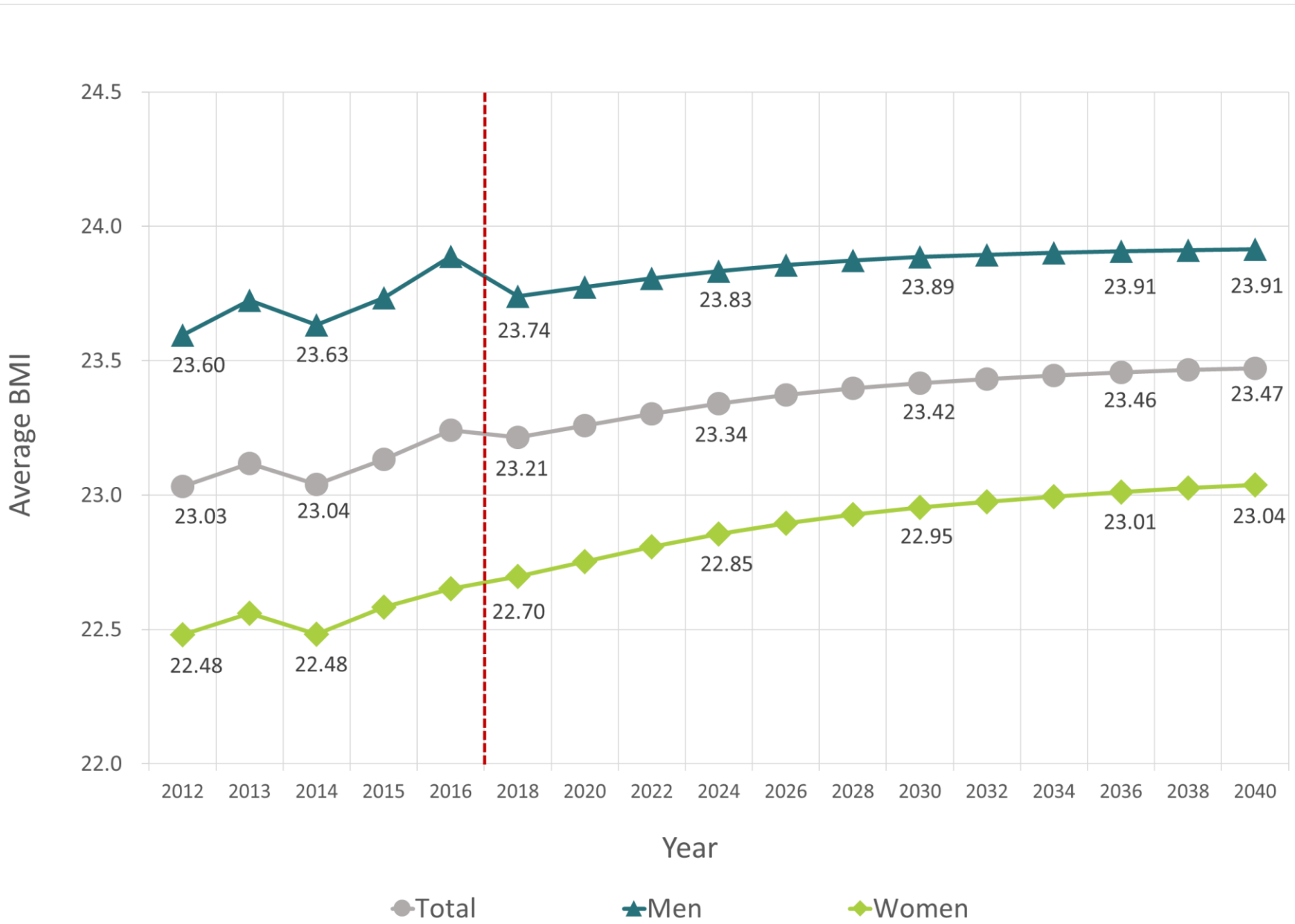
Figure 2 Population Health Model (POHEM) projections of average BMI in South Korea, 2012-2040

Figure 3A Projection of distribution of BMI, Men aged 19 years and older, South Korea, 2012-2040

Figure 3B Projection of distribution of BMI, Women aged 19 years and older, South Korea, 2012-2040

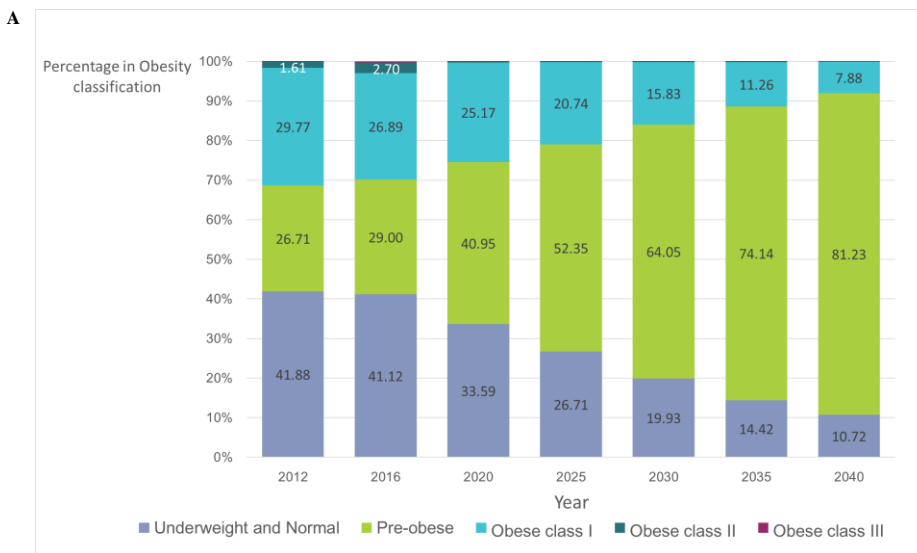
Figure 1 Summary of data sources and methods used to generate and validate projections of distribution of BMI categories in South Korea, 2012-2040





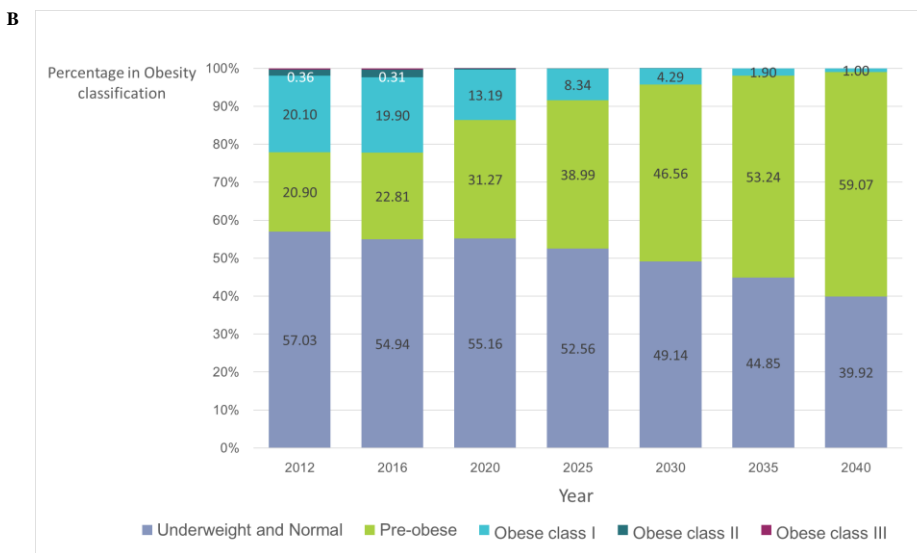
● Total ▲ Men ◆ Women

Figure 3 Projection of distribution of BMI, (A) Men and (B) Women, aged 19 years and older, South Korea, 2012-2040



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Figure 3 Projection of distribution of BMI, (A) Men and (B) Women, aged 19 years and older, South Korea, 2012-2040



2

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-8
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	6-7
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	7-8
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	6-8
		(b) Describe any methods used to examine subgroups and interactions	7
		(c) Explain how missing data were addressed	7-8
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	7-8
		(e) Describe any sensitivity analyses	-

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60**Results**

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9-11
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9-11
		(b) Indicate number of participants with missing data for each variable of interest	9-11
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	9-11
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	11
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	-
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	-
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-11
		(b) Report category boundaries when continuous variables were categorized	8
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-

Discussion

Key results	18	Summarise key results with reference to study objectives	12
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	14
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	12-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	14

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15
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*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Projecting the prevalence of obesity in South Korea through 2040: a microsimulation modeling approach

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Primary Subject Heading:	Public health
Secondary Subject Heading:	Health policy
Keywords:	PUBLIC HEALTH, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PREVENTIVE MEDICINE

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1 **Title: Projecting the prevalence of obesity in South Korea through 2040: a**
2 **microsimulation modeling approach**

3
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22 **Keywords:** Microsimulation, body mass index, obesity, Population Health Model, South
23 Korea

24

25 **Word count:** 4,337

ABSTRACT

Objective To project the future prevalence of obesity among populations 19 years and older by 2040 in South Korea

Design, setting, and participants Using the ‘Population Health Model-Body Mass Index’ (BMI) microsimulation model, the prevalence of obesity in Korean adults 19 years and over was projected until the year 2040. The model integrates individual survey data from the Korea Health Panel Survey of 2011 and 2012, population statistics based on resident registration, population projections, and complete life tables categorized by sex and age. Birth rate, life expectancy, and international migration were based on a medium growth scenario. The base population of Korean adults in 2012, devised through data aggregation, was 39,842,730. Prediction equations were formulated using BMI as the dependent variable; the individual’s sex, age, smoking status, physical activity, and the preceding year’s BMI were used as predictive factors.

Outcome measure BMI categorized by sex.

Results The median BMI for Korean adults in 2040 was forecast to be 23.55 kg/m² (23.97 and 23.17 kg/m² for men and women, respectively). According to the Korean BMI classification, 70.05% of all adults were forecast to be ‘pre-obese’ (i.e., have BMIs 23 to 24.9) by 2040 (81.23% of men and 59.07% of women), followed by 24.88% who would be ‘normal’.

Conclusions We explored the possibility of applying and expanding on the concept of microsimulation in the field of healthcare by combining data sources available in Korea using the POHEM model. In future studies, it is necessary to develop a microsimulation model suitable for Korea’s domestic situation, and it is necessary to evaluate the effectiveness of special health policies by applying various prediction scenarios to the basic model.

Strengths and limitations of this study

- To the best of our knowledge, this study is the first to use a microsimulation model to predict future obesity prevalence in Korea considering the change in population structure (macro level) as well as individual health behavior components (micro level).
- This study has the greatest significance in exploring the possibility of applying and expanding the concept of microsimulation in the field of healthcare by combining data sources available in Korea.
- Although a representative data source was used in this study, the prevalence of obesity may be underestimated because it is based on a self-reported BMI value.
- The estimated BMI value differs from the Korea Health Statistics, which is based on the data measured by actual measurement.
- There is a limitation that it does not accurately reflect the domestic situation because it borrows a micro-simulation model developed abroad.

80 BACKGROUND

81 The prevalence of overweight and obesity has increased markedly over the past 3 decades, and
82 concerns about health risks associated with obesity have become almost universal.[1] The increasing
83 rate of obesity is a growing public health concern not only in Western countries but also in South
84 Korea.[2] From the 1990s through the beginning of the new millennium, the prevalence of adult and
85 child obesity has increased rapidly and continues to rise steadily in parallel with rapid social and
86 economic development.[3]

87 Obesity is not only a major public health problem in and of itself, but also a factor in the
88 development of many chronic diseases; hence, it constitutes a strain on individuals and health systems
89 worldwide. In the Global Burden of Disease Study,[4] globally in 2017, a high body mass index
90 (BMI) accounted for 4.72 million deaths and 148.0 million disability-adjusted life-years. It is
91 associated with an increased risk of many disorders, including diabetes, hypertension, dyslipidemia,
92 heart disease, stroke, sleep apnea, early death, and cancer.[5-9] Moreover, obesity among older people
93 increases the risk of knee osteoarthritis[10] and reduces functional capacity and quality of life.[11-14]
94 The prevalence of these conditions rises commensurate with increased obesity, [15-18] and are
95 associated with significant morbidity, higher risks of mortality, and increased economic costs for both
96 individuals and the society at large.[19]

97 Meanwhile, with respect to worldwide comparisons, whether cutoff points for overweight
98 and obesity should be lower for Asians than for another ethnic group remains debated.[20] Because of
99 racial differences, the World Health Organization has proposed regarding BMIs of 18.5–22.9 kg/m² as
100 optimal, 23–24.9 kg/m² as overweight, 25–29.9 kg/m² as moderate obesity, and ≥30 kg/m² as severe
101 obesity for Asians.[21] However, it is more important to determine particular BMI values that
102 increase the likelihood of developing particular chronic disease, depending on the sex and age of the
103 individual. The Korean Society of Obesity, which was established to improve obesity management
104 through research and education, revised its clinical practical guidelines for the prevention and
105 treatment of obesity in 2018. The new guidelines renamed the “overweight” category to “pre-obese”,
106 and divided obesity into 3 categories, thereby aiming to highlight the risk of obesity instead of
107 promoting the term “overweight.” The most recent guidance is based in part on data from of

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3 108 84,690,131 Korean adults extracted from the Korean National Health Insurance Service Health
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5 109 Checkup Database between 2006 and 2015. By including the entire population registered in the
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7 110 National Health Insurance Service Database, they calculated the first and second cutoff points
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9 111 corresponding to the increased risk of any of 3 accompanying diseases (type 2 diabetes, hypertension,
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11 112 and dyslipidemia). The first and second BMI cutoff levels were reported to be 23 kg/m² and 25 kg/m²,
12
13 113 respectively, [22,23] suggesting that obesity criteria reflecting the actual risk of chronic disease in
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15 114 Koreans is necessary.

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18 115 A study of data from the National Health Insurance Service in Korea found that the
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20 116 socioeconomic cost of obesity in 2016 was approximately 9,665.32 million US dollars; medical
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22 117 expenses accounted for 51.3% of this amount, followed by decreasing productivity (20.5%),
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24 118 productivity loss (13.1%), early mortality (10.0%), care costs (4.3%), and transportation costs
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26 119 (0.8%).[24] Several studies on the long-term trends of obesity prevalence in South Korea found that
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28 120 obesity is increasing in men but not in women.[25-27] Although numerous investigators in other
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30 121 countries have attempted to predict the prevalence of obesity into the future, only one such study by
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32 122 Inkyung Baik was recently performed in South Korea.[2] More recent trends still need to be
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34 123 investigated through predictive studies, and the accurate prediction of obesity prevalence remains an
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36 124 important public health-related goal in the country. To efficiently establish and execute an effective
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38 125 healthcare policy, which would require a large budget, it is necessary to select future targets for policy
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40 126 interventions (such as high-risk groups) to predict future healthcare needs and prevent budget waste.

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43 127 Past prediction models incorporated a country's entire population; as such, macroscopic
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45 128 inferences based on average projections for the future society were generalized. However, when
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47 129 establishing a healthcare policy, it is necessary to estimate the future disease burden and medical
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49 130 needs of the entire population based on future projections that reflect individual characteristics,
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51 131 because a real-world understanding of the factors that are influenced by the policies or institutions is
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53 132 required. Individuals are independent entities with different characteristics and needs that govern their
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55 133 future decisions and behaviors. By applying these needs to the healthcare sector, health-related
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57 134 projections can be modeled by reflecting health risk factors such as sex, age, life cycle activities,
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59 135 smoking, etc.; as such, the effects of policy interventions can be quantified.[28] In this study, we

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3 136 aimed to predict the prevalence of obesity in Korea by using microsimulation, which is optimal for
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5 137 considering individual properties.

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7 138 Microsimulation is a modeling technique that typically uses individual microunits, each with
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9 139 its own set of properties, to simulate downstream events based on the probability of transition
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11 140 between predefined states and their changes over time. When used in medicine, microsimulation can
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13 141 be particularly powerful because it preserves the patterns of previous behaviors and conditions, and
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15 142 allows for a clearer representation and understanding of how various processes affect the total
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17 143 outcome of the population over time. In other words, microsimulation can predict the burden of
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19 144 disease by modeling various health risk factors that occur during an individual's lifetime. Given
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21 145 macro-effects such as changes in population structures in the forecasting model, microsimulation is
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23 146 very useful in that it can estimate both disease burdens and medical needs across the country.[28]
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25 147 Collecting individual events from within a population that has varying attributes can be used to
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27 148 predict and plan outcomes (such as incidence, prevalence, and cost), and can also be used to assess the
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29 149 clinical and cost effectiveness of alternative health interventions.[29] Microsimulation modeling is
30
31 150 particularly useful for studying BMI trends because it can simultaneously explain population
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33 151 dynamics such as aging, migration, and mortality. Additionally, the longitudinal framework of these
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35 152 models allows for interpreting a person's change in BMI as it is affected by factors such as a person's
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37 153 physical activity and behavior and thus act as a contributing factor to other diseases. [30] However,
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39 154 while microsimulation models have been steadily evolving across health- and economy-related fields
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41 155 in many European countries,[31] they have yet to be actively utilized in South Korea (especially for
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43 156 healthcare).

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47 157 Obesity prevalence and trend estimates provide important information for research, policy,
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49 158 and intervention.[32] As mentioned above, it is necessary to estimate the magnitude of obesity
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51 159 because it has been identified as a risk factor for various chronic diseases. Because health forecasting
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53 160 predicts disease episodes and portends future events, it facilitates healthcare strategies by promoting
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55 161 the setting of goals to reduce obesity, establish health promotion interventions, and optimize resource
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57 162 allocation.[33] Obesity trends may also be used to urge governments to implement preventative
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59 163 approaches to reducing obesity.[34] Based on the above, we performed this study to project the future

164 trends in obesity prevalence in South Korea up to the year 2040.

165

166 **METHODS**

167 **Model**

168 We used the Population Health Model (POHEM)-BMI to estimate the prevalence of obesity
169 in adults 19 years and over in South Korea from 2012 through 2040. In brief, POHEM is a time-
170 continuous, population-based, dynamic microsimulation model with individual underlying units of
171 analysis used worldwide. Dynamic microsimulation, in the context of social science and population
172 health, is a simulation of individuals (i.e., micro-level) and their behaviors, statuses, and actions
173 (dynamics) over time.[35] These are modeled as desired using multiple sources of empirical data,
174 including cross-sectional surveys, administrative databases, vital statistics, and census data.[36]
175 Through dynamic simulation, POHEM creates a population and ages it, one person at a time, until
176 death.[37] The model dynamically simulates an individual's disease state, risk factors, and health
177 determinants to describe and plan health outcomes.[36] POHEM is accessible because it wants the
178 general process to be constant across the country's population, with the exception of variables unique
179 to each country, such as marriage and mortality. The POHEM models include cardiovascular disease,
180 various cancers, osteoarthritis, physical activity, and neurological events. The model used in this study
181 was the POHEM-BMI; the performance of each prediction step is shown in Figure 1.

182 [Insert Figure 1 here]

183 **Base population**

184 To create the base population for the POHEM-BMI model, we used the 2011- 2012 Korea Health
185 Panel survey and the resident registration-based population statistics. This constituted the base
186 population for POHEM-BMI (n=39,842,730), reflecting the Korean population. Each Korean
187 respondent 19 years of age and over (n=11,501) in 2012 was replicated using their survey-recorded
188 weights to generate a simulated cohort of approximately 39,842,730 individuals. Korea Health Panel
189 survey data are nationally representative panel surveys that incorporate health status, chronic diseases,
190 health risk behaviors, and socio-demographic characteristics. Among them, we extracted sex, age,
191 current smoking status, physical activity, and the previous and current years' BMI values; these

192 variables were required for the predictive equation. We then used a multiple linear regression model
193 to estimate the BMI value using the independent variables age, sex, smoking status, physical activity,
194 and previous BMI value as predictors. The POHEM-BMI model is auto-regressive and includes
195 previous BMI values as a main explanatory variable.[30] For comparison with other international
196 studies using this model, the variable composition was the same, but the variable definition was not.
197 The definition of variables was consistent with the definition of indicators in the Korea Health
198 Statistics. In terms of predictor definitions, a current smoker was an individual who reported smoking
199 'every day' or 'sometimes'. Practicing physical activity was defined as performing either intense
200 physical activity for at least 10 continuous minutes a day, 20 minutes total per day, 3 days a week
201 during the preceding week, or moderate physical activity for at least 30 minutes a day, 5 days a week
202 during the preceding week.

203 **Simulation: Annual updates and risk transition**

204 The population makeup was updated by aging each person by 1 year and changing the total
205 population size based on population statistics, population projections, and complete life tables
206 categorized by sex and age from Statistics Korea. For population projections, we assumed a medium
207 growth scenario in terms of birth rate, life expectancy, and international migration. Each person's
208 BMI was updated annually by applying a predictive equation that incorporates his/her own
209 characteristics. The transition probability for each stochastic characteristic was calculated based on a
210 generalized linear model.

211 Similar to the original POHEM-BMI, we assumed that the current individual behavioral
212 patterns persisted, and no new factors arose to prevent obesity. We also assumed that the attributes of
213 19-year-old individuals, which were entered annually, remained similar year-to-year.

214 **Model validation and calibration**

215 We established the model's validity by comparing the projected BMI median obtained from
216 the prediction model to estimates obtained from the Korea Health Panel survey. We set the calibration
217 cutoff point to 5% and adjusted the model by comparing the difference between the median BMI
218 estimates observed from the Korea Health Panel survey and the values derived from the prediction
219 model categorized by sex and age. We analyzed the BMIs of each group by comparing the 2016 data

220 available from the Korea Health Panel with the most recent data. We accepted a difference of less
 221 than 5% overall as well as in the sex- and age-categorized groups. Finally, we adjusted the
 222 demographics of the 2040 population so that the predictions were similar within a 5% margin of error.
 223 In this study, all necessary data for model building and projection were obtained from publicly
 224 available data and does not include any identifiable personal information, so no additional ethical
 225 approval was required. In addition, ethical and governance approvals were granted by the Korea
 226 Institute for Health and Social Affairs which conducts Korea Health Panel Survey. All participants
 227 gave written informed consent to take part before they were allowed to complete the survey.

228

229 **Projection**

230 The model projected the BMI of each person from 2017 to 2040. Based on demographic
 231 characteristics, the projections were then aggregated by year for each of the predefined subgroups.
 232 The various trends observed in the Korean population data were used to generate algorithms that were
 233 applied to future projections.

234 **Model outputs**

235 The final results of the BMI distributions were calculated overall and by sex. Individuals with a BMI
 236 ≥ 25 kg/m² were obese according to the Guidelines for the Management of Obesity in Korean, which
 237 is not the internationally accepted standard (see Table 1). According to this guideline, BMI is
 238 categorized into standard groupings for underweight (<18.5 kg/m²), normal weight (18.5–22.9 kg/m²),
 239 pre-obese (23–24.9 kg/m²), obese class I (25–29.9 kg/m²), obese class II (30–34.9 kg/m²), and
 240 obese class III (≥ 35 kg/m²). All analyses in this study were performed using STATA version 13
 241 (StataCorp LLC, College Station, TX, USA).

242

243 **Table 1** BMI classification of South Korea

Classification	Body mass index (kg/m ²)
Underweight	< 18.5

Normal	18.5 – 22.9
Pre-obese	23 – 24.9
Obese class I	25 – 29.9
Obese class II	30 – 34.9
Obese class III	≥ 35

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245 Patient and public involvement

246 No patient involved

247

248 RESULTS

249 We compared the total numbers of the individuals and characteristics in the initial 2012
 250 population to those in the projected 2040 population (see Table 2) There were 39,842,730 adults who
 251 were 19 or over in 2012 and 43,818,808 in 2040. The male:female ratio was nearly 1:1 in both 2012
 252 and 2040. The rapid aging of the Korean population was clearly observed when comparing the 2 eras.
 253 The average age of adults was expected to increase by 10.9 years from 45.69 years in 2012 to 56.59
 254 years in 2040 (from 44.57 to 55.54 years among men and from 46.77 to 57.63 years among women).
 255 In 2012, the proportion of young people (those in the 19–39 and 40–64 year age groups combined)
 256 accounted for approximately 85.54% of the adult population, while the proportion of individuals aged
 257 65 years and older was relatively low at approximately 14%. However, the age group structure in
 258 South Korea 28 years later (2040) is predicted to be quite different, as the proportion of individuals
 259 19–64 years (i.e., the working age population) was only 60.95% of the adult population, while the
 260 proportion of the elderly population (≥65 years) was estimated to be almost 40% of the total adult
 261 population.

262

263 **Table 2** Comparison of number of people, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>						<i>Projected population (2040)</i>					
	Men		Women		Total		Men		Women		Total	
	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)
Number of people	19,709,628		20,133,102		39,842,730		21,717,128		22,101,680		43,818,808	
Age (mean±s.d.)	44.57±15.60		46.77±16.92		45.69±16.31		55.54±18.60		57.63±19.33		56.59±19.00	
19-39	7,985,737	(40.52)	7,505,824	(37.29)	15,491,561	(38.88)	4,873,740	(22.45)	4,588,867	(20.76)	9,462,607	(21.60)
40-64	9,360,489	(47.49)	9,230,871	(45.85)	18,591,360	(46.66)	8,896,886	(40.97)	8,349,634	(37.78)	17,246,520	(39.35)
65-	2,363,402	(11.98)	3,396,407	(16.87)	5,759,809	(14.45)	7,946,502	(36.59)	9,163,179	(41.45)	17,109,681	(39.05)
Smoking status												
Smoker	8,879,037	(45.05)	450,946	(2.24)	9,329,983	(23.42)						
Non-smoker	10,830,591	(54.95)	19,682,156	(97.76)	30,512,747	(76.58)						
Physical activity												
Physical activity	5,199,273	(26.38)	3,103,036	(15.41)	8,302,309	(20.84)						
Physical inactivity	14,510,355	(73.62)	17,030,066	(84.59)	31,540,421	(79.16)						

264 There was no significant difference between the median BMIs in 2012 and 2040; however, according to the BMI classification in South Korea, approximately

265 41.48% of the adult population was 'normal' in 2012, whereas only 24.88% of the population was predicted to be the same in 2040. (see Table 3) On the

266 other hand, the 'pre-obese' group was expected to account for approximately 70% of the total adult population.

267 **Table 3** Comparison of number of people, by BMI classification, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>						<i>Projected population (2040)</i>					
	Men		Women		Total		Men		Women		Total	
	Number	(Percent age)	Number	(Percent age)	Number	(Percentage)	Number	(Percent age)	Number	(Percentage)	Number	(Percentage)
BMI (median)	23.59		22.41		23.04		23.97		23.17		23.55	
Number of people by BMI classification												
Underweight	840,251	(4.26)	2,368,051	(11.76)	3,208,302	(8.05)	98,954	(0.46)	152,500	(0.69)	251,454	(0.57)
Normal	7,414,311	(37.62)	9,114,015	(45.27)	16,528,326	(41.48)	2,228,567	(10.26)	8,671,481	(39.23)	10,900,048	(24.88)
Pre-obese	5,264,866	(26.71)	4,207,673	(20.90)	9,472,539	(23.77)	17,641,668	(81.23)	13,055,482	(59.07)	30,697,150	(70.05)
Obese class I	5,867,369	(29.77)	4,046,607	(20.10)	9,913,976	(24.88)	1,712,332	(7.88)	221,829	(1.00)	1,934,161	(4.41)
Obese class II	318,297	(1.61)	324,205	(1.61)	642,502	(1.61)	33,455	(0.15)	388	(0.00)	33,843	(0.08)
Obese class III	4,534	(0.02)	72,551	(0.36)	77,085	(0.19)	2,152	(0.01)	0	(0.00)	2,152	(0.00)

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3 270 The model was well calibrated in both the initial population and from 2017 to 2040.
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5 271 Differences in each of the variables estimated between 2013 to 2016, which were derived from the
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7 272 Korea Health Panel data, were within the 5% range only when using the predictive model.
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9 273 Additionally, when compared to the population structure for 2040 (the final year) as predicted by
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11 274 Statistics Korea, the total population and gender and age-specific ratio were similar.

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13 275 Figure 2 shows the median predicted BMIs between 2017 and 2040. Each median BMI value
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15 276 from 2013 to 2016 was estimated from the Korea Health Panel survey. The median BMI for the entire
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17 277 adult population is predicted to increase very slightly from 23.23 kg/m² in 2018 to 23.53 kg/m² in
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19 278 2036 and is expected to remain steady thereafter. The predicted median BMI trends are similar for
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21 279 men; the median BMI in adult men was projected to increase only slightly, from 23.74 kg/m² in 2018
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23 280 to 23.95 kg/m² in 2036 and then almost plateau thereafter. On the other hand, women were expected
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25 281 to experience a relatively steep rise compared to men; the median BMI in adult women was projected
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27 282 to increase from 22.66 kg/m² in 2018 to 23.17 kg/m² in 2040.

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30 283 [Insert Figure 2 here]

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32 284 The BMI distributions for men and women from 2012 to 2040 are shown in Figure 3. The
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34 285 proportions of 'pre-obese' individuals in both sexes are predicted to increase dramatically over time,
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36 286 while the proportions of individuals who are classified as 'normal' and 'obese' will gradually
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38 287 decrease. As of 2025, 52.35% of all male adults were expected to be pre-obese, with that proportion
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40 288 expected to be close to 81.23% by 2040. Moreover, 53.24% of all adult women are expected to be
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42 289 'pre-obese' by 2035, with the proportion rising to almost 59.078% by 2040.

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45 290 [Insert Figure 3A and 3B here]

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48 49 292 **DISCUSSION**

50
51 293 The purpose of this study was to predict the prevalence of obesity in South Korea in the year
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53 294 2040 using a microsimulation model. In this study, we strove to predict future adult obesity rates in
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55 295 South Korea using the POHEM-BMI, which is developed by Statistics Canada. Summarizing the
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57 296 predicted results, the median BMI of South Korea's adult population aged 19 years and older was
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59 297 expected to be 23.55 in 2040, while the percentage of 'pre-obese' individuals was expected to

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3 298 increase over time. While it is encouraging that the proportion of 'obese' people (i.e., those with
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5 299 BMIs ≥ 25 kg/m²) in 2040 is predicted to be much lower than that in 2012, it is discouraging that the
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7 300 proportion of 'normal' individuals is also markedly lower. Most notably, the pre-obesity rate is
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9 301 predicted to rise dramatically. In addition to the sex and age of each individual, our model includes
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11 302 only smoking and physical activity as health-related behaviors. The distributions of these factors were
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13 303 assumed to remain equal across the years; hence, our data show that maintaining smoking and
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15 304 physical activity rates at 2012 levels among adults will lead to a sharp increase in the 'pre-obese'
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17 305 population by 2040.

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20 306 To our knowledge, the only other study that predicted future obesity rates among South
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22 307 Korean adults was the aforementioned investigation by Baik.[2] That study explored factors affecting
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24 308 adult obesity as well as abdominal obesity, and constructed forecasting models to predict obesity
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26 309 prevalence rates in 2020 and 2030 using the Korea National Health and Nutritional Examination
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28 310 Survey (KNHANES). The prevalence rates of obesity among men and women in that study were
29
30 311 predicted to be 47% and 32%, respectively, in 2020 and 62% and 37%, respectively, in 2030; these
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32 312 data were inconsistent with our own. The differences appeared to be caused by the different secondary
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34 313 sources used in the 2 studies, as well as the different independent variables and prediction
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36 314 methodologies. In particular, the obesity rate in the initial population according to the KNHANES
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38 315 tended to be higher; as such, a higher initial prevalence rate would lead to a higher projection.[38]
39
40 316 Most importantly, Baik's study did not consider the preceding year's BMI, which was a major
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42 317 independent variable in our study; this may be a major explanation for the differences in findings
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44 318 between the 2 studies. We also compared our results to those predicted in Canada using the same
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46 319 model we used; based on self-reported BMIs, approximately 59% of the adult Canadian population
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48 320 was predicted to be 'overweight or obese' (i.e., BMIs > 25 kg/m²) by 2030, which is a much higher
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50 321 percentage than that predicted in South Korea (10.12%).

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52
53 322 With reference to international comparisons, if the international BMI standard were to be
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55 323 applied in our study, the results would be much more favorable given that a large proportion of
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57 324 subjects would be classified as normal. However, this study defined obesity by applying the BMI
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59 325 classification system according to 2018 Korean Society for the Study of Obesity guideline for the

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3 326 management of obesity in Korea. Of course, it would be appropriate to use international standards in
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5 327 international comparison, but it is necessary to reflect the situation of individual countries in the
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7 328 management of obesity for the purpose of preventing and managing chronic diseases. Therefore,
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9 329 rather than emphasizing the BMI classification criteria, more research is needed to analyze the BMI
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11 330 values that can significantly predict the occurrence of chronic diseases. In other words, it is necessary
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13 331 to continuously accumulate sufficient epidemiologic evidence for the relationship between the BMI
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15 332 and the actual risk of disease and death for Koreans, and based on such evidence, efforts to establish
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17 333 appropriate diagnostic and medical standards for Koreans are needed. In particular, the relationship is
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19 334 likely to vary by age as well as sex, so it should be considered as well. In the meantime, the obesity
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21 335 standard has been applied collectively regardless of sex and age. However, in order to deviate from a
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23 336 uniform approach to obesity, gender- and age-based approaches are needed, considering the changes
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25 337 in hormones and body composition.

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28 338 Because health management policies including obesity management requires a large budget,
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30 339 it is most important to establish cost-effective policies, and this requires selecting targets for policy
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32 340 intervention. The results from this study made it possible to grasp the obese high-risk group by sex
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34 341 and age group, and furthermore, it is expected to enable estimation of medical needs. As it is
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36 342 necessary to apply obesity standards differently according to sex and age group, it is a similar problem
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38 343 in setting goals of the 'National Health Promotion Comprehensive Plan'. The developing
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40 344 governmental 'National Health Promotion Comprehensive Plan' needs to suggest additional, wider-
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42 345 ranging goals considering the characteristics of each sex and age group, rather than presenting goals
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44 346 for obesity prevalence among adult men and women. In this case, the goal should be presented at an
45
46 347 achievable level in consideration of future prediction patterns. Finally, systematic public health
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48 348 interventions that are tailored to individual characteristics need to be established.

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51 349 Findings from this study should be interpreted with consideration of several limitations.
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53 350 First, since a microsimulation model for predicting obesity prevalence has not been developed in this
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55 351 country, we borrowed the model developed by the Statistics Canada, and accordingly it is not built to
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57 352 fit the domestic situation. Therefore, not only is the definition of obesity different, but the predictors
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59 353 of BMI include only sex, age, smoking, physical activity, and preceding year's BMI values. In the

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3 354 future, research to develop a new model of microsimulation in the field of healthcare for domestic
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5 355 conditions will be very valuable. In this process, it is necessary to consider practical suitability and
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7 356 efficiency in selecting basic data, module-specific behavioral equations, and variables for use in the
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9 357 model. Second, it is a limitation of data sources. There is a difference between the current prevalence
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11 358 of obesity calculated from the Korea Health Panel data used in this study and the Korea Health
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13 359 Statistics using the KNHANES. As of 2011, the prevalence of adult obesity in Korea Health Statistics
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15 360 was 31.9%, and the prevalence of adult obesity calculated by the Korea Health Panel data was 23.7%,
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17 361 a difference of 8.2%.[39] Unlike the Korea Health Statistics, which contains body-measured height
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19 362 and weight information, the Korea Health Panel (although this is a representative data source)
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21 363 generates data based on self-reported by respondents, which may underestimate obesity. However, in
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23 364 the POHEM-BMI model used in this study, the BMI of the previous year was regarded as the main
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25 365 explanatory variable, and therefore, the Korea Health panel data that followed the same subject once a
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27 366 year was inevitably used. In addition, the original POHEM-BMI model includes the process of
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29 367 converting self-reported BMI into a measured BMI, but we omitted this due to limitations of the data
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31 368 source.

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35 369 Nevertheless, our study's importance is that it is the first to examine the possibility of using
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37 370 microsimulation to predict future BMI medians in South Korea. Additionally, it is important to note
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39 371 that the BMI of the future adult population was predicted after considering the change in population
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41 372 structure at the macro level as well as individual health behavior components at the micro level.

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44 374 **CONCLUSION**

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47 375 The key finding of this study is that by 2040, 70.05% of Korean adults are predicted to be
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49 376 pre-obese. Utilizing data sources available in Korea, the possibility of applying and expanding on the
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51 377 concept of microsimulation was explored. In future studies, a model suitable for South Korea needs to
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53 378 be developed, and the effectiveness of specific health policies ought to be assessed by applying
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55 379 various relevant scenarios to the basic forecasting model.

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58 381 **Abbreviations**

382 BMI: body mass index; KNHANES: Korea National Health and Nutritional Examination
383 Survey, POHEM: Population Health Model

384 **Authors' Contributions**

385 YS (the first author) designed the study, analyzed and interpreted the data, and wrote the
386 paper. YE participated in the statistical analysis. DS provided assistance in the interpretation of the
387 data and preparation of the manuscript. SJ (the corresponding author) directed this study. All authors
388 read and approved the final version of the manuscript.

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392 agency had no role in the study design, analysis and interpretation of the data, or the preparation of
393 the manuscript.

394 **Competing Interests**

395 The authors declare that they have no competing interests.

396 **Ethics approval**

397 This study used publicly available data of Korea Health Panel Survey 2011-2012 from The
398 Korea Institute for Health and Social Affairs and the National Health Insurance, population statistics
399 based on resident registration, population projections, complete life tables and future mortality rates
400 from Statistics Korea. The dataset does not contain any identifiable personal information. Ethical
401 approval was given by the Institutional Review Board of Korea University, Seoul, Korea (IRB No.
402 KUIRB-2020-0018-01).

403 **Provenance and peer review** Not commissioned; externally peer reviewed.

404 **Data sharing statement**

405 The Korea Health Panel Survey data used in this article is available in
406 <https://www.khp.re.kr:444/eng/data/data.do>. Detailed information on the survey design and data
407 characteristics are provided at <https://www.khp.re.kr:444/eng/survey/sampling.do>. Population
408 statistics, population projections, and complete life tables are available from <http://kosis.kr/eng/>.

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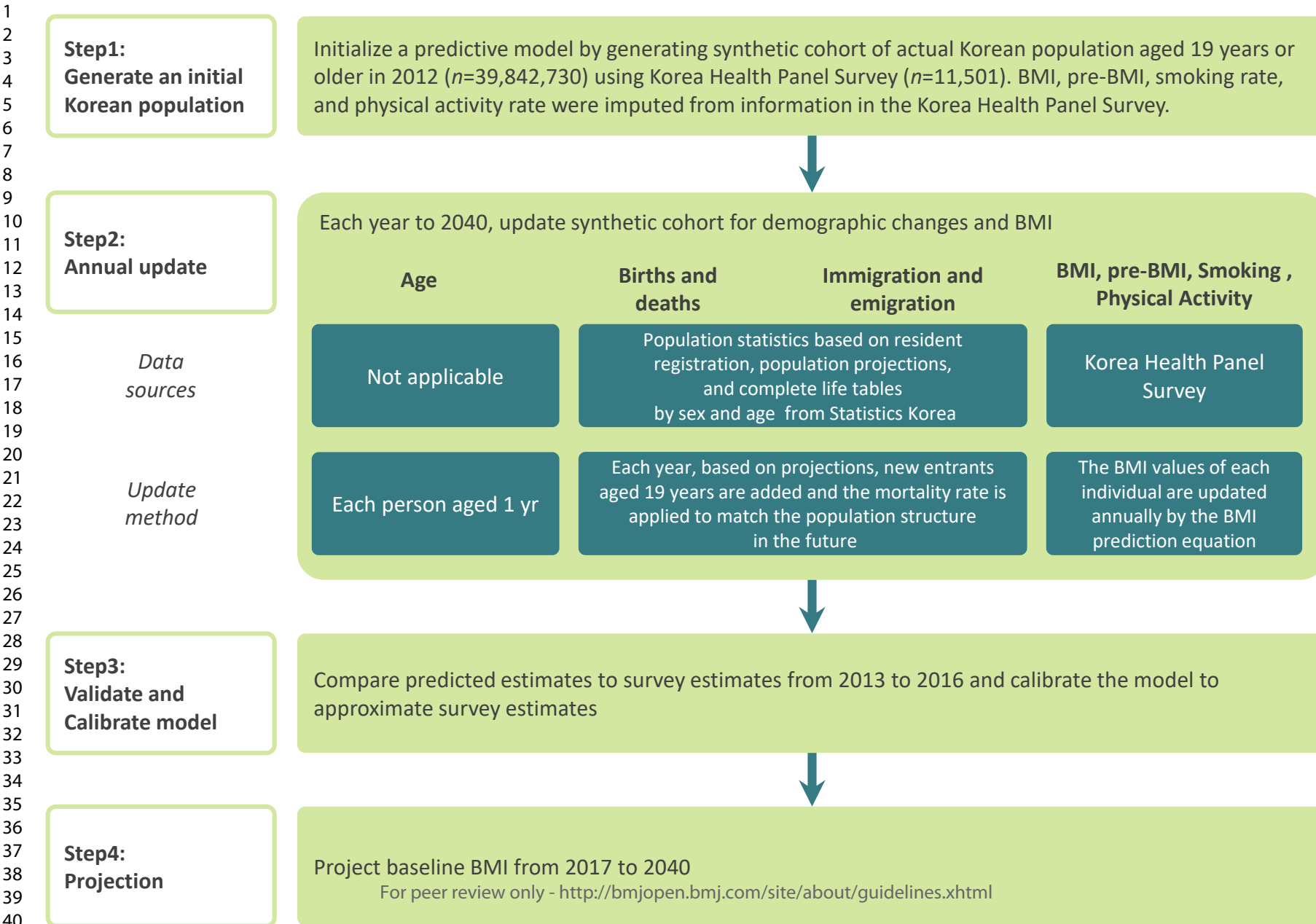
Figure 1 Summary of data sources and methods used to generate and validate projections of distribution of BMI categories in South Korea, 2012-2040

Figure 2 Population Health Model (POHEM) projections of median BMI in South Korea, 2012-2040

Figure 3A Projection of distribution of BMI, Men aged 19 years and older, South Korea, 2012-2040

Figure 3B Projection of distribution of BMI, Women aged 19 years and older, South Korea, 2012-2040

Figure 1 Summary of data sources and methods used to generate and validate projections of distribution of BMI categories in South Korea, 2012-2040



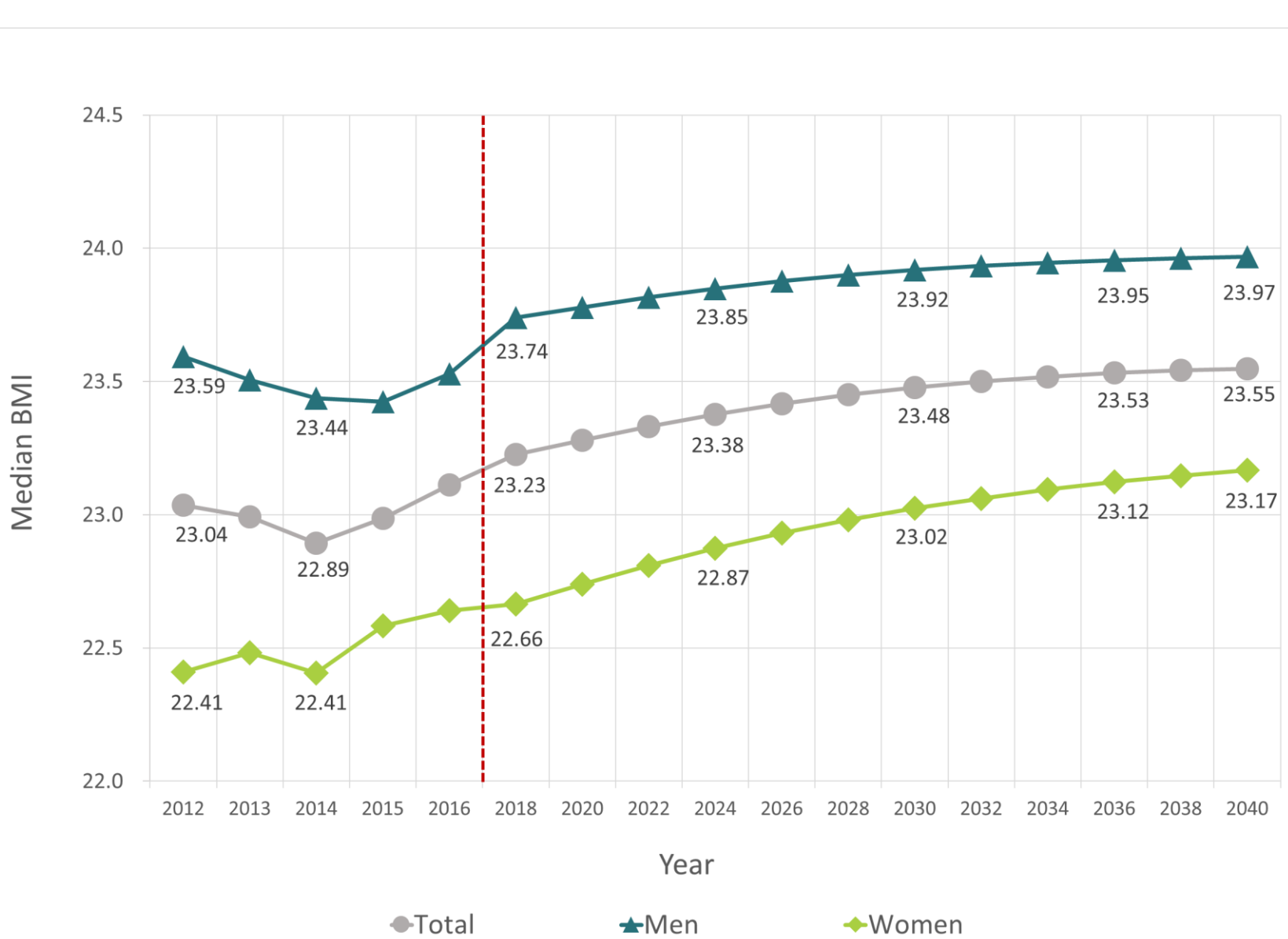


Figure 3 Projection of distribution of BMI, (A) Men and (B) Women, aged 19 years and older, South Korea, 2012-2040

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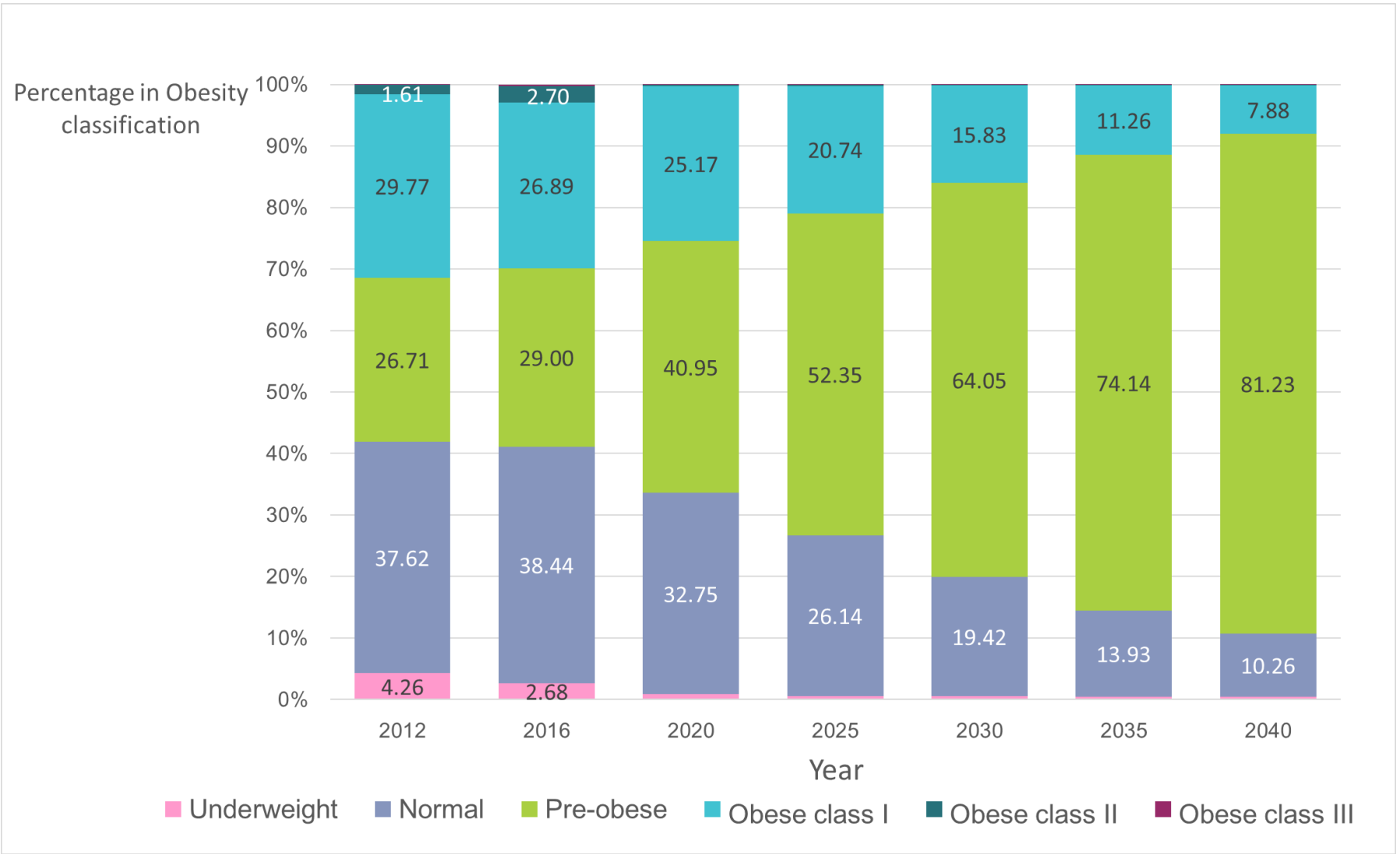
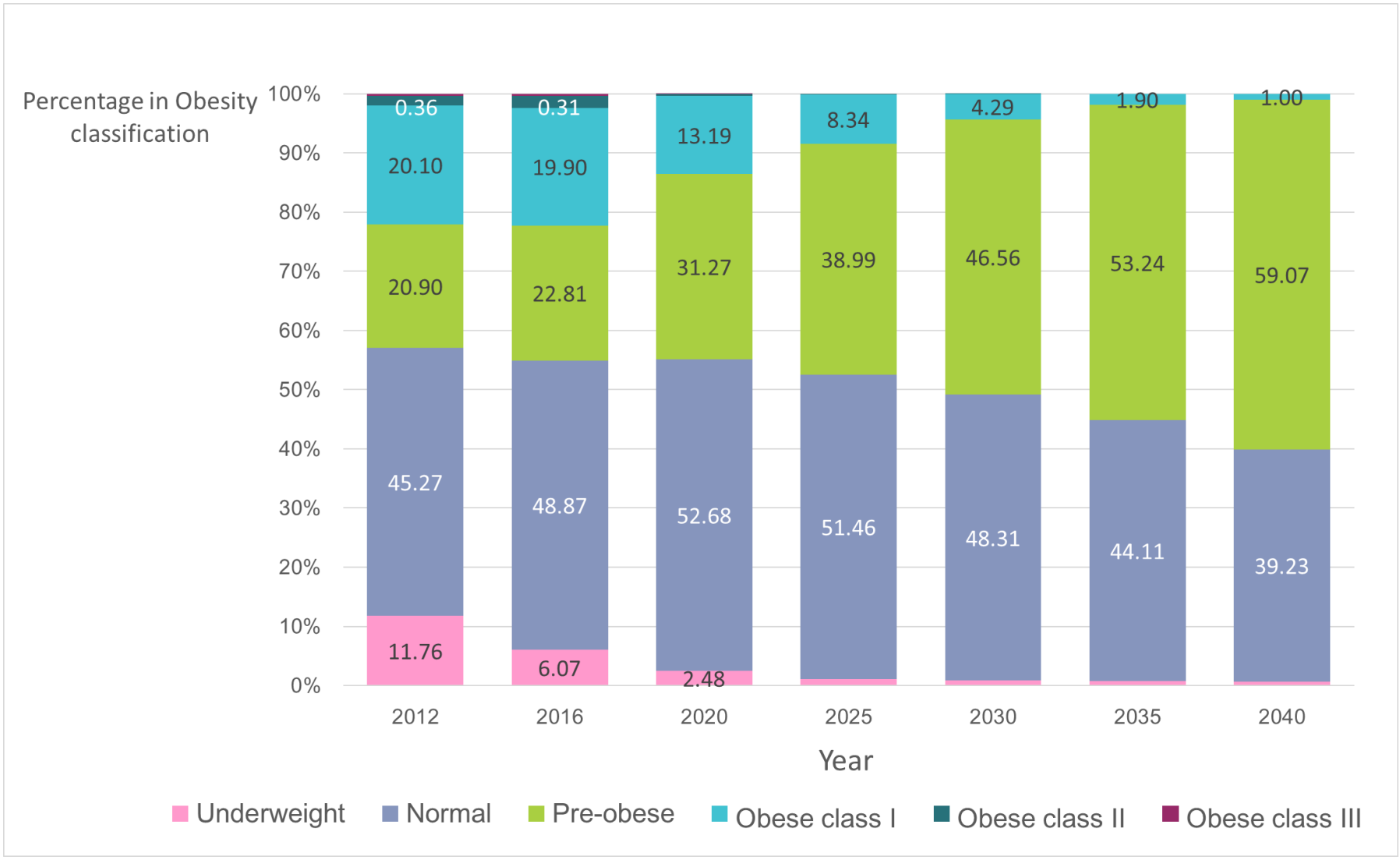


Figure 3 Projection of distribution of BMI, (A) Men and (B) Women, aged 19 years and older, South Korea, 2012-2040

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-7
Objectives	3	State specific objectives, including any prespecified hypotheses	6-7
Methods			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	8-9
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9
Bias	9	Describe any efforts to address potential sources of bias	8-9
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-9
		(b) Describe any methods used to examine subgroups and interactions	8-9
		(c) Explain how missing data were addressed	8-9
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	8-9
		(e) Describe any sensitivity analyses	-

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10-13
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10-12
		(b) Indicate number of participants with missing data for each variable of interest	10-12
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	10-12
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	13
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	-
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	-
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-12
		(b) Report category boundaries when continuous variables were categorized	11
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
Discussion			
Key results	18	Summarise key results with reference to study objectives	13-14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-16
Generalisability	21	Discuss the generalisability (external validity) of the study results	15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Projecting the prevalence of obesity in South Korea through 2040: a microsimulation modeling approach

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Primary Subject Heading:	Public health
Secondary Subject Heading:	Health policy
Keywords:	PUBLIC HEALTH, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PREVENTIVE MEDICINE

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1 **Title: Projecting the prevalence of obesity in South Korea through 2040: a**
2 **microsimulation modeling approach**

3
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21 **Keywords:** Microsimulation, body mass index, obesity, Population Health Model, South

22 Korea

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24 **Word count:** 4,373

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ABSTRACT

Objective To project the prevalence of obesity in 2040 among individuals 19 years and older in South Korea.

Design, setting, and participants Using the ‘Population Health Model-Body Mass Index’ (POHEM-BMI) microsimulation model, the prevalence of obesity in Korean adults 19 years and older was projected until 2040. The model integrated individual survey data from the Korea Health Panel Survey of 2011 and 2012, population statistics based on resident registration, population projections, and complete life tables categorized by sex and age. Birth rate, life expectancy, and international migration were based on a medium growth scenario. The base population of Korean adults in 2012, devised through data aggregation, was 39,842,730. The prediction equations were formulated using BMI as the dependent variable; the individual’s sex, age, smoking status, physical activity, and preceding year’s BMI were used as predictive factors.

Outcome measure BMI categorized by sex.

Results The median BMI for Korean adults in 2040 was forecast to be 23.55 kg/m² (23.97 and 23.17 kg/m² for men and women, respectively). According to the Korean BMI classification, 70.05% of all adults were forecast to be ‘pre-obese’ (i.e., have BMIs 23 to 24.9) by 2040 (81.23% of men and 59.07% of women) and 24.88% to be ‘normal’.

Conclusions We explored the possibility of applying and expanding on the concept of microsimulation in the field of healthcare by combining data sources available in Korea and found that more than half of the adults in this study population will be pre-obese, and the proportions of “obesity” and “normal” will decrease compared with those in 2012. The results of our study will aid in devising healthy strategies and spreading public awareness for preventing this condition.

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Strengths and limitations of this study

- To the best of our knowledge, this is the first study to use a microsimulation model to predict future obesity prevalence in Korea considering the change in population structure (macro level) as well as individual health behavior components (micro level).
- The results of our study aid in suggesting additional and wider-ranging strategies for obesity prevention by considering sex and age group in the formulation of the ‘National Health Promotion Comprehensive Plan’.
- Although a representative data source was used in this study, the prevalence of obesity may be underestimated because it is based on a self-reported BMI value.
- This study uses a micro-simulation model developed abroad, and hence, may not reflect the domestic situations accurately.
- Another limitation is that we assumed the attributes of 19-year-old individuals to remain similar each year.

67 **BACKGROUND**

68 The prevalence of overweight and obesity has increased markedly over the past 3 decades,
69 and concerns about health risks associated with obesity have become almost universal.[1]

70 The increasing rate of obesity is a growing public health concern not only in Western
71 countries but also in South Korea.[2] From the 1990s through the beginning of the new
72 millennium, the prevalence of adult and child obesity has increased rapidly and continues to
73 rise steadily in parallel with rapid social and economic development.[3]

74 Obesity is not only a major public health problem in itself, but also a factor in the
75 development of many chronic diseases; hence, it constitutes a strain on individuals and health
76 systems worldwide. It is associated with an increased risk of many disorders, including
77 diabetes, hypertension, dyslipidemia, heart disease, stroke, sleep apnea, early death, and
78 cancer.[4-8] Moreover, obesity among older people increases the risk of knee
79 osteoarthritis[9] and reduces functional capacity and quality of life.[10-13] The prevalence of
80 these conditions rises in proportion to the increase in obesity[14-17] and is associated with
81 increased economic costs for both individuals and the society at large.[18] A study of data
82 from the National Health Insurance Service in Korea found that the socioeconomic cost of
83 obesity in 2016 was approximately 9,665.32 million US dollars.[19]

84 Meanwhile, with respect to worldwide comparisons, whether cutoff points for
85 overweight and obesity should be lower for Asians than for another ethnic groups remains
86 debatable.[20] The World Health Organization has proposed BMIs of 18.5–22.9 kg/m² as
87 optimal, 23–24.9 kg/m² as overweight, 25–29.9 kg/m² as moderate obesity, and ≥ 30 kg/m²
88 as severe obesity for Asians.[21] The Korean Society of Obesity, which was established to
89 improve obesity management through research and education, revised its clinical practical
90 guidelines for the prevention and treatment of obesity in 2018. The new guidelines renamed
91 the “overweight” category to "pre-obese", and divided obesity into 3 categories, thereby

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3 92 aiming to highlight the risk of obesity instead of promoting the term "overweight." The most
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5 93 recent guidance is based in part on data of 84,690,131 Korean adults extracted from the
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8 94 Korean National Health Insurance Service Health Checkup Database between 2006 and 2015.
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10 95 By including the entire population registered in the National Health Insurance Service
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12 96 Database, they calculated the first and second cutoff points corresponding to the increased
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14 97 risk of any of the 3 accompanying diseases (type 2 diabetes, hypertension, and dyslipidemia)
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16 98 The first cutoff BMI level was 23 kg/m², and the second cutoff BMI level was 25 kg/m²,
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18 99 suggesting the necessity of obesity criteria that accurately reflect the risk of chronic disease
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21 100 among Koreans.[22,23]

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24 101 Although numerous investigators in other countries have attempted to predict the
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26 102 future prevalence of obesity, only one such study by Inkyung Baik was recently performed in
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28 103 South Korea.[2] More recent trends still need to be investigated through predictive studies,
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30 104 and the accurate prediction of obesity prevalence remains an important public health-related
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32 105 goal in the country. To efficiently establish and execute an effective healthcare policy, which
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34 106 would require a large budget, it is necessary to select future targets for policy interventions
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36 107 (such as high-risk groups) to predict healthcare needs and prevent budget waste.
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40 108 Past prediction models incorporated a country's entire population; as such,
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42 109 macroscopic inferences based on average projections for the future society were generalized.
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44 110 However, when establishing a healthcare policy, it is necessary to estimate the future disease
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46 111 burden and medical needs of the entire population based on future projections that reflect
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48 112 individual characteristics because a real-world understanding of factors that are influenced by
49
50 113 policies or institutions is required. Individuals are independent entities with different
51
52 114 characteristics and needs that govern their future decisions and behaviors. By applying these
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54 115 needs, health-related projections can be modeled to reflect health risk factors such as sex,
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56 116 age, life cycle activities, smoking, etc., and the effects of policy interventions can be
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3 117 quantified.[24] In this regard, we aimed to predict the prevalence of obesity in Korea by
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5 118 using microsimulation, which is optimal for considering individual properties.
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8 119 Microsimulation is a modeling technique, which typically uses individual microunits,
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10 120 each with its own set of properties, to simulate downstream events based on the probability of
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12 121 transition between predefined states and their changes over time. When used in medicine,
13
14 122 microsimulation can be particularly powerful because it preserves the patterns of previous
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16 123 behaviors and conditions, and allows for a clearer representation and understanding of how
17
18 124 various processes affect the total outcome of the population over time.[25] Given macro-
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20 125 effects such as changes in population structures in the forecasting model, microsimulation is
21
22 126 very useful as it can estimate both disease burdens and medical needs across the country.[24]
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24 127 Microsimulation modeling is particularly useful for studying BMI trends because it can
25
26 128 simultaneously explain population dynamics such as aging and mortality. Additionally, the
27
28 129 longitudinal framework of these models allows for interpreting a person's change in BMI as
29
30 130 it is affected by factors such as a person's physical activity and behavior, and thus, acts as a
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32 131 contributing factor for other diseases.[26] However, while microsimulation models have been
33
34 132 steadily evolving across health- and economy-related fields in many European countries,[27]
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36 133 they are yet to be actively utilized in South Korea (especially for healthcare).
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42 134 Obesity prevalence and trend estimates provide important information for research,
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44 135 policy, and intervention.[28] Because health forecasting predicts disease episodes and
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46 136 portends future events, it facilitates healthcare strategies by promoting the setting of goals to
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48 137 reduce obesity, establish health promotion interventions, and optimize resource
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50 138 allocation.[29] Obesity trends may also be used to urge governments to implement
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52 139 preventative approaches for reducing obesity.[30] Based on the above findings, we performed
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54 140 this study to project the future trends in obesity prevalence in South Korea up to the year
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56 141 2040.
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5 143 **METHODS**6
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8 144 **Model**

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10 145 We used the Population Health Model (POHEM)-BMI to estimate the prevalence of
11
12 146 obesity among adults 19 years and older in South Korea from 2012 through 2040. In brief,
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14 147 POHEM is a time-continuous, population-based, dynamic microsimulation model with
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16 148 individual underlying units of analysis used worldwide. Dynamic microsimulation, in the
17
18 149 context of social science and population health, is a simulation of individuals (i.e., micro-
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20 150 level) and their behaviors, statuses, and actions (dynamics) over time.[31] These are modeled
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22 151 as desired using multiple sources of empirical data, including cross-sectional surveys,
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24 152 administrative databases, vital statistics, and census data.[32]
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26 153 Through dynamic simulation, POHEM creates a population and ages it, one person at a time,
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28 154 until death.[33] The model dynamically simulates an individual's disease state, risk factors,
29
30 155 and health determinants to describe and plan health outcomes.[32] POHEM is accessible
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32 156 because it wants the general process to be constant across the country's population, with the
33
34 157 exception of variables unique to each country, such as marriage and mortality. The POHEM
35
36 158 models include cardiovascular disease, various cancers, osteoarthritis, physical activity, and
37
38 159 neurological events. The model used in this study was the POHEM-BMI; the performance of
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40 160 each prediction step is shown in Figure 1.

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47 161 **Base population**

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49 162 To create the base population for the POHEM-BMI model, we used the 2011–2012 Korea
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51 163 Health Panel survey and the resident registration-based population statistics. The base
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53 164 population for POHEM-BMI (n=39,842,730), reflected the Korean population. Each Korean
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55 165 respondent 19 years of age and older (n=11,501) in 2012 was replicated using their survey-
56
57 166 recorded weights to generate a simulated cohort of approximately 39,842,730 individuals.
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3 167 Korea Health Panel survey data are nationally representative, and incorporate health status,
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5 168 chronic diseases, health risk behaviors, and socio-demographic characteristics. Among them,
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8 169 we extracted sex, age, current smoking status, physical activity, and the previous and current
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10 170 years' BMI values; these variables were required for the predictive equation. We then used a
11
12 171 multiple linear regression model to estimate the BMI value using the extracted independent
13
14 172 variables as predictors. The POHEM-BMI model is auto-regressive and includes previous
15
16 173 BMI values as a main explanatory variable.[26] For comparison with other international
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18 174 studies using this model, the variable composition was the same, but the variable definition
19
20 175 was not. The definition of variables was consistent with the definition of indicators in the
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22 176 Korea Health Statistics. A current smoker was an individual who reported smoking 'every
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24 177 day' or 'sometimes'. Practicing physical activity was defined as performing either intense
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26 178 physical activity for at least 10 continuous minutes a day, 20 minutes total per day, 3 days a
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28 179 week during the preceding week, or moderate physical activity for at least 30 minutes a day,
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30 180 5 days a week during the preceding week. Height and weight, which are components of BMI,
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32 181 were based on self-reported data.

182 **Simulation: Annual updates and risk transition**

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38 183 The study population was updated by aging each person by 1 year and changing the total
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40 184 population size based on population statistics, population projections, and complete life tables
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42 185 categorized by sex and age from Korean Statistics. For population projections, we assumed a
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44 186 medium growth scenario in terms of birth rate, life expectancy, and international migration.
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46 187 Each person's BMI was updated annually by applying a predictive equation that incorporates
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48 188 his/her own characteristics. The transition probability for each stochastic characteristic was
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50 189 calculated based on a generalized linear model.

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56 190 We assumed that the current individual behavioral patterns persisted, and no new
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58 191 factors arose to prevent obesity, like the original POHEM-BMI. We also assumed that the
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3 192 attributes of 19-year-old individuals, which were entered annually, remained similar each
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5 193 year.

8 194 **Model validation and calibration**

10 195 We established the model's validity by comparing the projected BMI median
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12 196 obtained from the prediction model to estimates obtained from the Korea Health Panel
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14 197 survey. We set the calibration cutoff point to 5% and adjusted the model by comparing the
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16 198 difference between the median BMI estimates observed from the Korea Health Panel survey
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18 199 and the values derived from the prediction model categorized by sex and age. We analyzed
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20 200 the BMIs of each group by comparing the 2016 data available from the Korea Health Panel
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22 201 with the most recent data. We accepted a difference of less than 5% overall in the sex- and
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24 202 age-categorized groups. Finally, we adjusted the demographics of the 2040 population so that
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26 203 the predictions were within a 5% margin of error. In this study, all necessary data for model
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28 204 building and projection were obtained from publicly available data and does not include any
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30 205 identifiable personal information. Hence, no ethical approval was required, in addition to the
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32 206 ethical and governance approvals granted by the Korea Institute for Health and Social Affairs
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34 207 (KIHASA), which conducts the Korea Health Panel Survey. All participants gave written
35
36 208 informed consent before they completed the survey.

42 209 **Projection**

44 210 The model projected the BMI of each person from 2017 to 2040. Based on demographic
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46 211 characteristics, the projections were then aggregated by year for each of the predefined
47
48 212 subgroups. The various trends observed in the Korean population data were used to generate
49
50 213 algorithms that were applied to future projections.

54 214 **Model outputs**

56 215 The BMI distributions were calculated overall and by sex. Individuals with a BMI ≥ 25
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58 216 kg/m² were obese according to the Guidelines for the Management of Obesity in Korea,
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217 which is not the internationally accepted standard (Table 1). All analyses in this study were
 218 performed using STATA version 13 (StataCorp LLC, College Station, TX, USA).

219

220 **Table 1** BMI classification of South Korea

Classification	Body mass index (kg/m ²)
Underweight	< 18.5
Normal	18.5 – 22.9
Pre-obese	23 – 24.9
Obese class I	25 – 29.9
Obese class II	30 – 34.9
Obese class III	≥ 35

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222 **Patient and public involvement**

223 No patient involved

224

225 **RESULTS**

226 We compared the total number of the individuals and their characteristics in the
 227 initial 2012 population to those in the projected 2040 population (Table 2). There were
 228 39,842,730 adults who were 19 years of age or older in 2012 and 43,818,808 in 2040. The
 229 male: female ratio was nearly 1:1 in both 2012 and 2040. Rapid aging of the Korean
 230 population was clearly observed when comparing the 2 populations. The average age of
 231 adults was expected to increase by 10.9 years (from 45.69 years in 2012 to 56.59 years in

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3 232 2040 [from 44.57 to 55.54 years among men and 46.77 to 57.63 years among women]). In
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5 233 2012, the proportion of young people (those in the 19–39 and 40–64-year age groups
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7 234 combined) accounted for approximately 85.54% of the adult population, while the proportion
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9 235 of individuals aged 65 years and older was relatively low at approximately 14%. However,
10
11 236 the age group structure in South Korea 28 years later (2040) is predicted to be quite different,
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13 237 as the proportion of individuals 19–64 years (i.e., the working age population) was only
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15 238 60.95% of the adult population, while the proportion of the elderly population (≥ 65 years)
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17 239 was estimated to be almost 40% of the total adult population.
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241 **Table 2** Comparison of number of people, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>						<i>Projected population (2040)</i>					
	Men		Women		Total		Men		Women		Total	
	Number	Perce ntage	Number	Perce ntage	Number	Perce ntage	Number	Perce ntage	Number	Perce ntage	Number	Perce ntage
Number of people	19,709,628		20,133,102		39,842,730		21,717,128		22,101,680		43,818,808	
Age (mean±s.d.)	44.57±15.60		46.77±16.92		45.69±16.31		55.54±18.60		57.63±19.33		56.59±19.00	
19-39	7,985,737	40.52%	7,505,824	37.29%	15,491,561	38.88%	4,873,740	22.45%	4,588,867	20.76%	9,462,607	21.60%
40-64	9,360,489	47.49%	9,230,871	45.85%	18,591,360	46.66%	8,896,886	40.97%	8,349,634	37.78%	17,246,520	39.35%
65 and above	2,363,402	11.98%	3,396,407	16.87%	5,759,809	14.45%	7,946,502	36.59%	9,163,179	41.45%	17,109,681	39.05%

Smoker	8,879,03	45.05	450,946	2.24%	9,329,983	23.42						
	7	%				%						
Physical activity	5,199,27	26.38	3,103,03	15.41	8,302,309	20.84						
	3	%	6	%		%						

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3 244 The model was well calibrated in both the initial population and from 2017 to 2040.
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5 245 Differences in each of the variables estimated between 2013 and 2016, which were derived
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7 246 from the Korea Health Panel data, were within the 5% range only when using the predictive
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9 247 model. Additionally, when compared to the population structure for 2040 (the final year) as
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11 248 predicted by Statistics Korea, the total population, gender, and age-specific ratio were similar.
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14 249 Figure 2 shows the median predicted BMIs between 2017 and 2040. Each median
15
16 250 BMI value from 2013 to 2016 was estimated from the Korea Health Panel survey. The
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18 251 median BMI for the entire adult population is predicted to increase very slightly from 23.23
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20 252 kg/m² in 2018 to 23.53 kg/m² in 2036 and is expected to remain steady thereafter. The
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22 253 predicted median BMI trends are similar for men; the median BMI in adult men was
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24 254 projected to increase only slightly, from 23.74 kg/m² in 2018 to 23.95 kg/m² in 2036 and then
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26 255 almost plateau thereafter. However, women were expected to experience a relatively steep
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28 256 rise compared to that of men; the median BMI in adult women was projected to increase from
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30 257 22.66 kg/m² in 2018 to 23.17 kg/m² in 2040.
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37 259 The BMI distributions for men and women from 2012 to 2040 are shown in Figure 3.
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39 260 There was no significant difference between the median BMIs in 2012 and 2040, but the
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41 261 results according to the BMI classifications showed large changes. The proportions of ‘pre-
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43 262 obese’ individuals in both sexes are predicted to increase dramatically over time, while the
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45 263 proportions of individuals who are classified as ‘normal’ and ‘obese’ will gradually decrease.
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47 264 As of 2025, 52.35% of all male adults were expected to be pre-obese, with that proportion
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49 265 expected to be close to 81.23% by 2040. Moreover, 53.24% of all women were expected to
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51 266 be ‘pre-obese’ by 2035, with the proportion rising to almost 59.07% by 2040.
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58 268 According to the BMI classification by age group, in South Korea, in 2012, about
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269 20.36% of the population aged 19-39 were 'pre-obese', but in 2040, it increased to 39.59%,
 270 almost double. The proportion of the 'normal' population was almost the same in 2012 and
 271 2040, and the 'obese class I' decreased by nearly half. However, in the population aged 40
 272 to 64 and over 65, the proportion of 'pre-obese' increased almost three times in 2040
 273 compared to that in 2012, and the proportion of 'normal' decreased to less than 20% (Table
 274 3).

275

276 **Table 3** Comparison of number of people, by BMI classification, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>			<i>Projected population (2040)</i>		
	19-39	40-64	65-	19-39	40-64	65-
Number of people	15,491,561	18,591,360	5,759,809	9,462,607	17,246,520	17,109,681
BMI (median)%	22.37	23.52	23.02	23.07	23.64	23.58
Distribution of people by BMI classification						
Underweight %	11.76	5.10	7.60	2.66	0.00	0.00
Normal %	45.66	37.81	42.12	45.68	19.89	18.40
Pre-obese %	20.36	26.51	24.10	39.59	76.60	80.31
Obese class I %	20.67	28.40	24.85	11.70	3.51	1.29
Obese class II %	1.51	1.79	1.30	0.36	0.00	0.00
Obese class III %	0.03	0.38	0.02	0.02	0.00	0.00

277 **DISCUSSION**

278 The purpose of this study was to predict the prevalence of obesity in South Korea in
279 the year 2040 using a microsimulation model. In this study, we strove to predict future adult
280 obesity rates in South Korea using the POHEM-BMI, which was developed by Statistics
281 Canada. Summarizing the predicted results, the median BMI of South Korea's adult
282 population aged 19 years and older was expected to be 23.55 in 2040, while the percentage of
283 'pre-obese' individuals was expected to increase over time. While it is encouraging that the
284 proportion of 'obese' people (i.e., those with BMIs ≥ 25 kg/m²) in 2040 is predicted to be
285 much lower than that in 2012, it is discouraging that the proportion of 'normal' individuals is
286 also markedly lower. Most notably, the pre-obesity rate is predicted to rise dramatically. In
287 addition to the sex and age variables, our model includes only smoking and physical activity
288 as health-related behaviors. The distributions of these factors were assumed to remain equal
289 across the years; hence, our data show that maintaining smoking and physical activity rates at
290 2012 levels among adults will lead to a sharp increase in the 'pre-obese' population by 2040.

291 To the best of our knowledge, the only other study that predicted future obesity rates
292 among South Korean adults was the investigation by Baik.[2] That study explored factors
293 affecting adult as well as abdominal obesity, and constructed forecasting models to predict
294 obesity prevalence rates in 2020 and 2030 using the Korea National Health and Nutritional
295 Examination Survey (KNHANES). The prevalence rates of obesity among men and women
296 in that study were predicted to be 47% and 32%, respectively, in 2020 and 62% and 37%,
297 respectively, in 2030; these data were inconsistent with our results. The differences in
298 prediction results appeared to be caused by the different secondary sources and prediction
299 models in the two studies. First, in Baik's study, a prediction model was constructed by
300 applying a linear regression model and an autoregressive integrated moving average model
301 using the KNHANES data. The dependent variable in the prediction model was BMI, and the

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2
3 302 independent variables included the survey year, age, marital status, job status, income status,
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5 303 smoking, alcohol consumption, sleep duration, psychological factors, dietary intake, and
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7 304 fertility rate. In contrast, in this study, the Korea Health Panel data was used as the data
8
9 305 source, and BMI was predicted by performing microsimulation with sex, age, smoking,
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11 306 physical activity, and previous years' BMIs as independent variables. Therefore, the method
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13 307 of measurement of the dependent variable, BMI differs between the studies; unlike the
14
15 308 KNHANES, which contains body-measured height and weight information, the Korea Health
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17 309 Panel (although this is a representative data source) generates data based on self-reported by
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19 310 respondents, which may underestimate obesity. Inevitably, the obesity rate in the initial
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21 311 population according to the KNHANES tended to be higher; as such, a higher initial
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23 312 prevalence rate would lead to a higher projection.[34]

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28 313 We also tried to compare the results from this study with the predicted estimate by
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30 314 country, but few studies have empirically predicted the prevalence of obesity in the future
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32 315 using simulation models. One study compiled nationally-representative data from various
33
34 316 sources and predicted the future prevalence of overweight and obesity in Indian adults aged
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36 317 20-69 years will reach 30.5% and 9.5% among men, 27.4% and 13.9% among women,
37
38 318 respectively, by 2040.[35] According to a study that estimated the prevalence of obesity in
39
40 319 the future through regression modeling, 42% of Americans were expected to be obese by
41
42 320 2030.[36] Similarly, a study that predicted the prevalence of obesity in Australian adults by
43
44 321 2025 using a multiple linear regression model predicted that 83% of male adults over the age
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46 322 of 20 and 75% of female adults would be overweight or obese.[37] In all three countries,
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48 323 India, the United States, and Australia, overweight and obesity were defined according to the
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50 324 classifications defined by the WHO, and much higher values were found than those in Korea.
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52 325 We also compared our results to those predicted in Canada using the same model, and 59% of
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54 326 the adult Canadian population was predicted to be 'overweight or obese' by 2030.
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3 327 This study defined obesity by applying the BMI classification system according to
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5 328 2018 Korean Society for the Study of Obesity guideline for the management of obesity in
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8 329 Korea. It would be appropriate to use international standards for comparison; however, it is
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10 330 necessary to reflect the situation of individual countries in the management of obesity for the
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12 331 purpose of preventing and managing chronic diseases. Therefore, rather than emphasizing the
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14 332 BMI classification criteria, more research is needed to determine the BMI values that can
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16 333 significantly predict the occurrence of chronic diseases. In other words, it is necessary to
17
18 334 continuously accumulate sufficient epidemiologic evidence for the relationship between the
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20 335 BMI and the actual risk of disease and death for Koreans, and based on such evidence, efforts
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22 336 to establish appropriate diagnostic and medical standards for Koreans are needed. In
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24 337 particular, the relationship is likely to vary by age and sex; hence, it should be considered too.
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26 338 Here, the obesity standard has been applied collectively regardless of sex and age. However,
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28 339 in order to deviate from a uniform approach to obesity, gender- and age-based approaches are
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30 340 needed, considering the changes in hormones and body composition.

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33 341 Because health management policies including obesity management require a large
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35 342 budget, it is most important to establish cost-effective policies. The results from this study
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37 343 made it possible to determine the obese high-risk group by sex and age group, and estimate
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39 344 medical needs. As it is necessary to apply obesity standards differently according to sex and
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41 345 age group, it is difficult to set the 'National Health Promotion Comprehensive Plan' goals.
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43 346 This plan needs to suggest additional, wider-ranging goals considering the characteristics of
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45 347 each sex and age group, rather than presenting goals for obesity prevalence among adult men
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47 348 and women. In this case, the goal should be presented at an achievable level in consideration
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49 349 of future prediction patterns. Finally, systematic public health interventions, which are
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51 350 tailored to individual characteristics need to be established.

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54 351 Findings from this study should be interpreted with consideration of several
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3 352 limitations. First, since a microsimulation model for predicting obesity prevalence has not
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5 353 been developed in this country, we borrowed the model developed by Statistics Canada, and
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7 354 it may not fit the domestic situation; nonetheless, we defined each variable in the predictive
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9 355 equation according to the operational definition in Korea Health Statistics. However, if the
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11 356 model is more suited to the domestic situation, besides sex, age, smoking, physical activity,
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13 357 and previous year's BMI value, various factors related to BMI may be added to the predictors
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15 358 of BMI. However, in this study, as we faithfully followed the existing model and explored the
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17 359 possibility of domestic application, the process of constructing a prediction equation was
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19 360 omitted. In the future, research to develop a new model of microsimulation in the field of
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21 361 healthcare for domestic conditions will be very valuable. In this process, it is necessary to
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23 362 consider practical suitability and efficiency in selecting basic data, module-specific
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25 363 behavioral equations, and variables for use in the model. Second, we had limited data
26
27 364 sources. There is a difference between the current prevalence of obesity calculated from the
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29 365 Korea Health Panel data used in this study and the Korea Health Statistics using the
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31 366 KNHANES. As of 2011, the prevalence of adult obesity in Korea Health Statistics was
32
33 367 31.9%, and the prevalence of adult obesity calculated by the Korea Health Panel data was
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35 368 23.7%, a difference of 8.2%.[38] As mentioned earlier in the difference between the results of
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37 369 Baik's study, this difference originated from the method of measuring BMI in the two data
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39 370 sources. However, in the POHEM-BMI model used in this study, the BMI of the previous
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41 371 year was regarded as the main explanatory variable, and therefore, the Korea Health panel
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43 372 data that followed the same participants once a year was inevitably used. In addition, the
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45 373 original POHEM-BMI model includes the process of converting self-reported BMI into a
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47 374 measured BMI, but we omitted this due to limitations of the data source. Third, we assumed
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49 375 that the attributes of 19-year-old individuals entered each year remain at a similar level each
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51 376 year. This means that the individual attributes of 19-year-old adults are the same for 29 years
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3 377 from 2012 to 2040; thus, it can be considered somewhat less realistic. In future studies, it is
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5 378 expected that more meaningful and realistic results will be derived if the model is constructed
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7 379 by reflecting the trend of changes in the attributes of the 19-year-old population and updating
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9 380 it according to the year.

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12 381 Nevertheless, our study is the first to examine the possibility of using
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14 382 microsimulation to predict future BMI medians in South Korea. Additionally, the BMI of the
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16 383 future adult population was predicted after considering the change in population structure at
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18 384 the macro level as well as individual health behavior components at the micro level.

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22 386 **CONCLUSION**

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25 387 The key finding of this study is that by 2040, 70.05% of Korean adults are predicted
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27 388 to be pre-obese. Utilizing data sources available in Korea, the possibility of applying and
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29 389 expanding on the concept of microsimulation was explored. In future studies, a model
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31 390 suitable for South Korea needs to be developed, and the effectiveness of specific health
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33 391 policies ought to be assessed by applying various relevant scenarios to the basic forecasting
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35 392 model.

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39 394 **Abbreviations**

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42 395 BMI: body mass index; KNHANES: Korea National Health and Nutritional
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44 396 Examination Survey, POHEM: Population Health Model

45 397 **Authors' Contributions**

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47 398 YS (the first author) designed the study, analyzed, and interpreted the data, and wrote
48
49 399 the paper. YE participated in the statistical analysis. DS aided in the interpretation of the data
50
51 400 and preparation of the manuscript. SJ (the corresponding author) directed this study. All
52
53 401 authors read and approved the final version of the manuscript.

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405 The funding agency had no role in the study design, analysis and interpretation of the data, or
406 the preparation of the manuscript.

407 Competing Interests

408 The authors declare that they have no competing interests.

409 Ethics approval

410 This study used publicly available data of Korea Health Panel Survey 2011-2012
411 from the Korea Institute for Health and Social Affairs and the National Health Insurance,
412 population statistics based on resident registration, population projections, complete life
413 tables and future mortality rates from Statistics Korea. The dataset does not contain any
414 identifiable personal information. Ethical approval was given by the Institutional Review
415 Board of Korea University, Seoul, Korea (IRB No. KUIRB-2020-0018-01).

416 Data sharing statement

417 The Korea Health Panel Survey data used in this article is available in
418 <https://www.khp.re.kr:444/eng/data/data.do>. Detailed information on the survey design and
419 data characteristics are provided at <https://www.khp.re.kr:444/eng/survey/sampling.do>.
420 Population statistics, population projections, and complete life tables are available from
421 <http://kosis.kr/eng/>.

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3 533 **Figure legends**
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5 534 **Figure 1** Summary of data sources and methods used to generate and validate projections of
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8 535 distribution of BMI categories in South Korea, 2012–2040
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10 536 **Figure 2** Population Health Model (POHEM) projections of median BMI in South Korea,
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12 537 2012–2040
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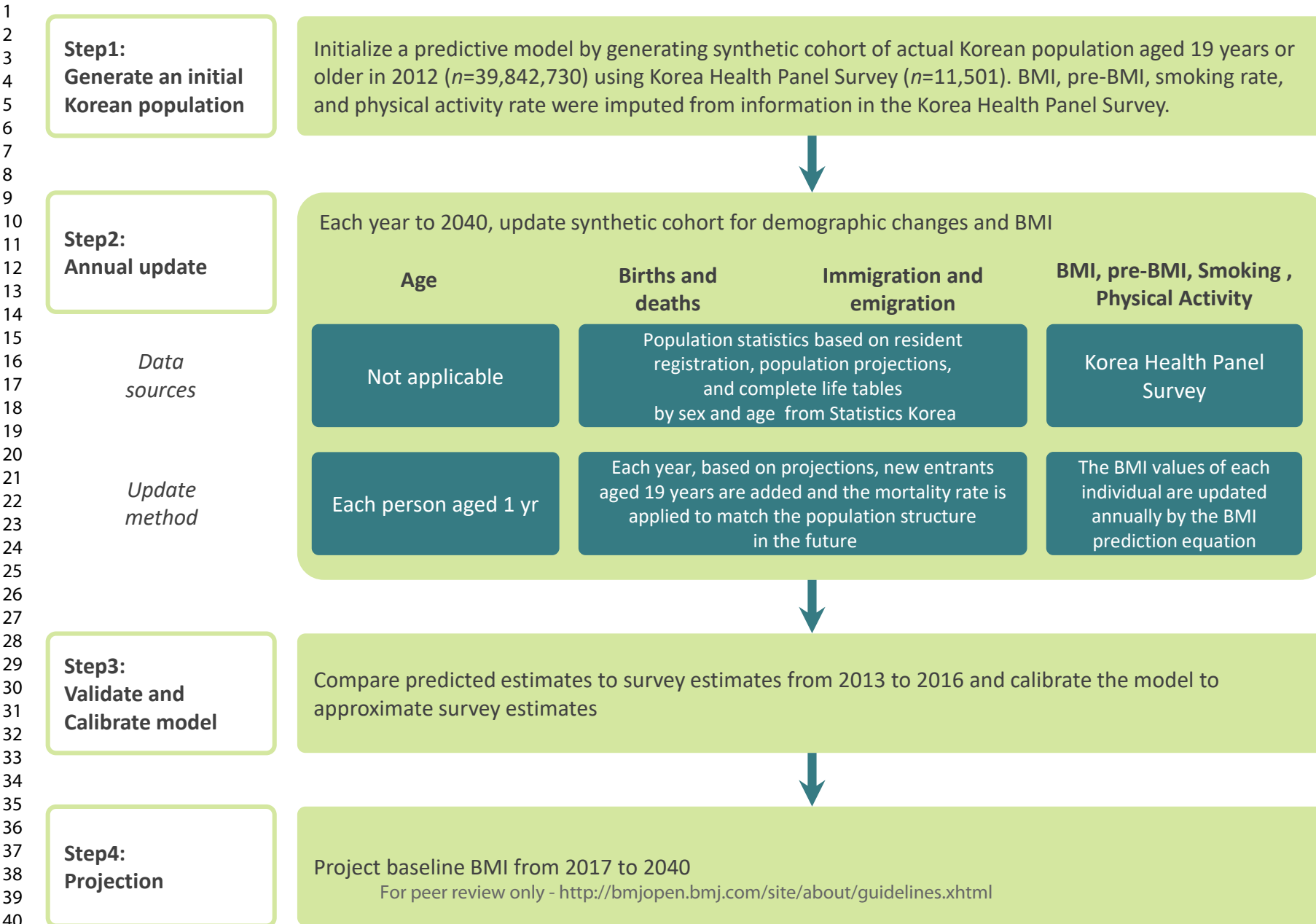
14 538 **Figure 3A** Projection of distribution of BMI, adults aged 19 years and older, South Korea,
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19 540 **Figure 3B** Projection of distribution of BMI, men aged 19 years and older, South Korea,
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24 542 **Figure 3C** Projection of distribution of BMI, women aged 19 years and older, South Korea,
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Figure 1 Summary of data sources and methods used to generate and validate projections of distribution of BMI categories in South Korea, 2012-2040



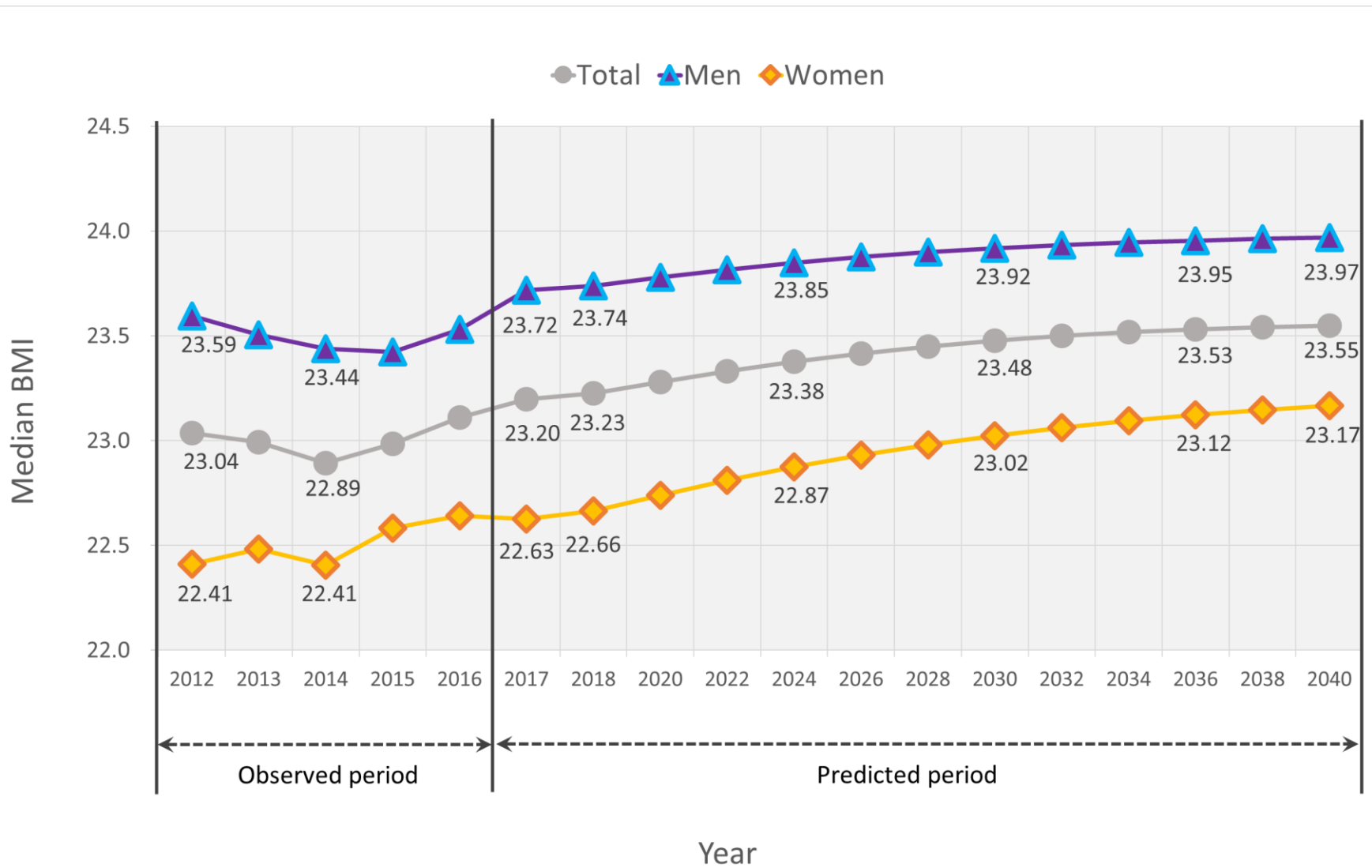


Figure 3 Projection of distribution of BMI, (A) Adults, (B) Men and (C) Women, aged 19 years and older, South Korea, 2012-2040

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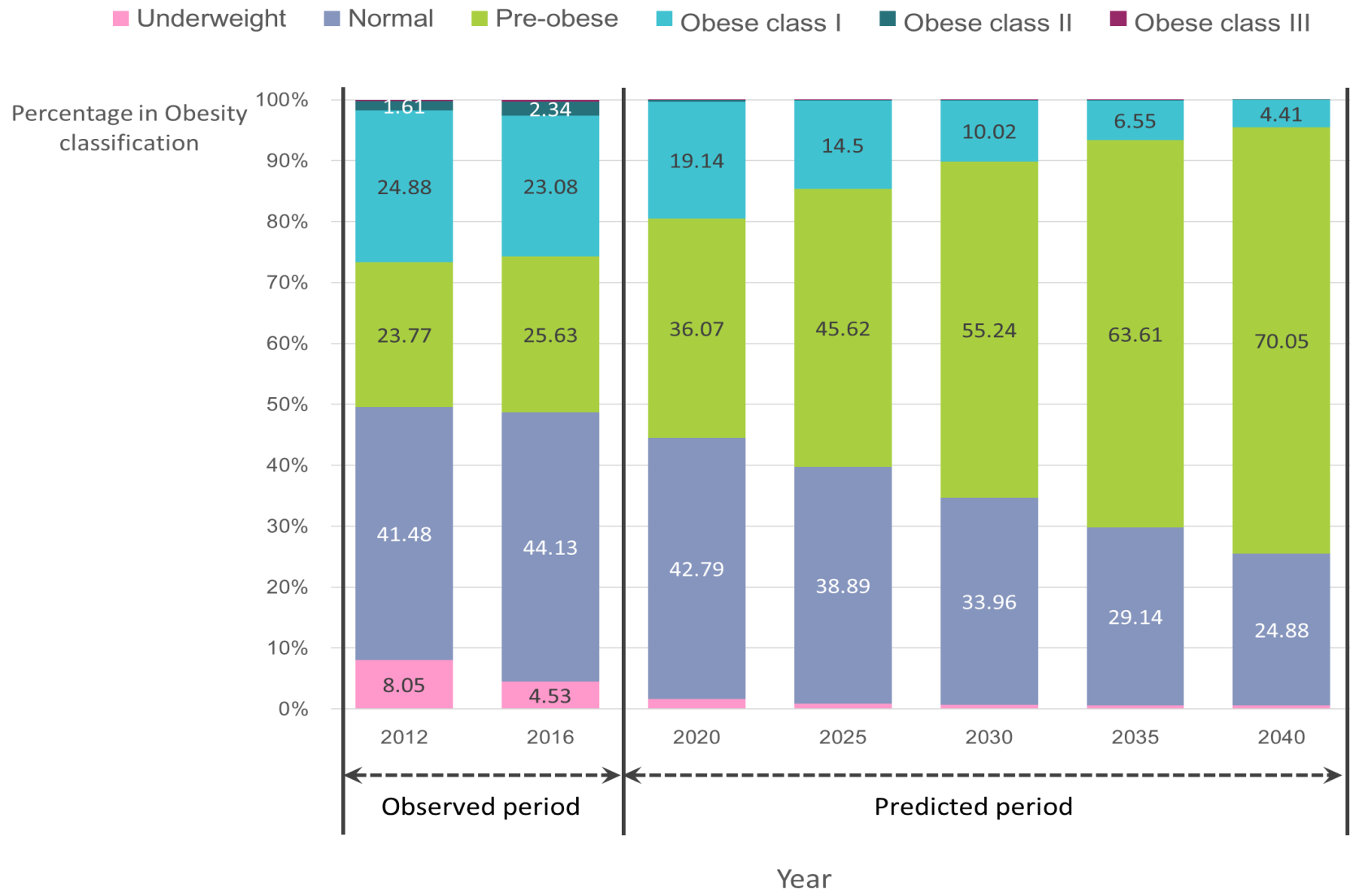
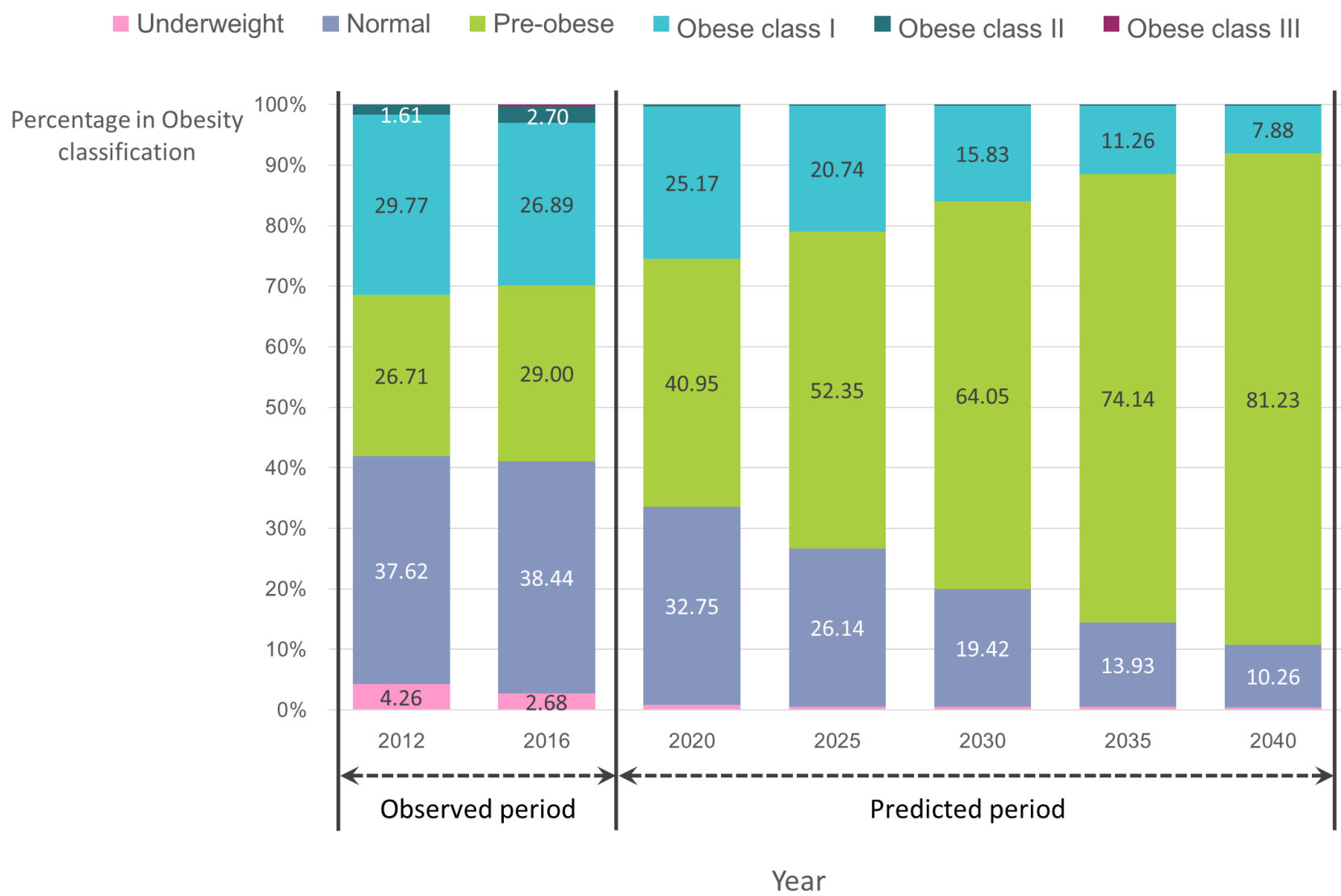


Figure 3 Projection of distribution of BMI, (A) Adults, (B) Men and (C) Women, aged 19 years and older, South Korea, 2012-2040

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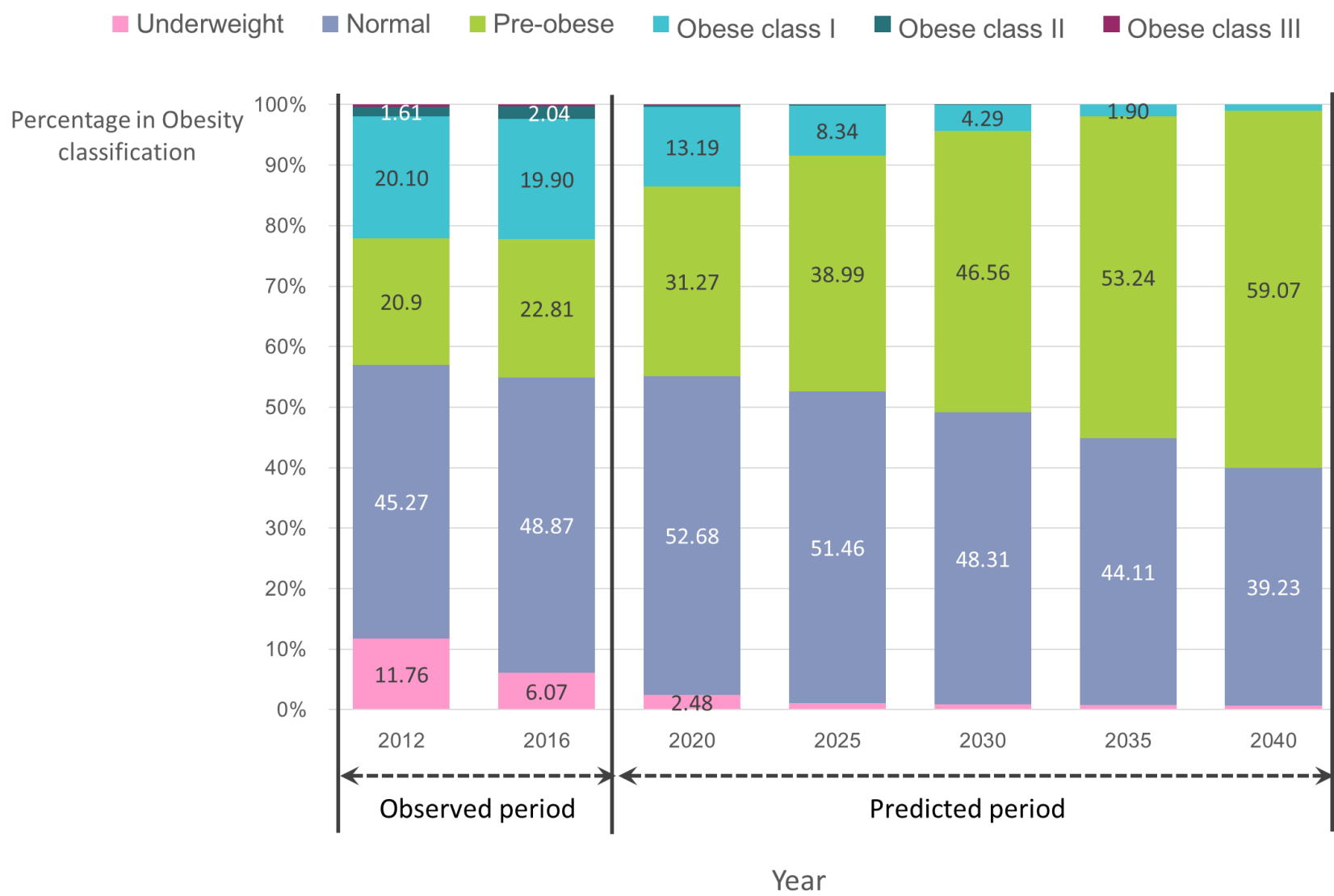


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Figure 3 Projection of distribution of BMI, (A) Adults, (B) Men and (C) Women, aged 19 years and older, South Korea, 2012-2040

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1 **Title: Projecting the prevalence of obesity in South Korea through 2040: a**
2 **microsimulation modeling approach**

3
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20
21 **Keywords:** Microsimulation, body mass index, obesity, Population Health Model, South

22 Korea

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24 **Word count:** 4,373

25

ABSTRACT

Objective To project the prevalence of obesity in 2040 among individuals 19 years and older in South Korea.

Design, setting, and participants Using the ‘Population Health Model-Body Mass Index’ (POHEM-BMI) microsimulation model, the prevalence of obesity in Korean adults 19 years and older was projected until 2040. The model integrated individual survey data from the Korea Health Panel Survey of 2011 and 2012, population statistics based on resident registration, population projections, and complete life tables categorized by sex and age. Birth rate, life expectancy, and international migration were based on a medium growth scenario. The base population of Korean adults in 2012, devised through data aggregation, was 39,842,730. The prediction equations were formulated using BMI as the dependent variable; the individual’s sex, age, smoking status, physical activity, and preceding year’s BMI were used as predictive factors.

Outcome measure BMI categorized by sex.

Results The median BMI for Korean adults in 2040 was forecast to be 23.55 kg/m² (23.97 and 23.17 kg/m² for men and women, respectively). According to the Korean BMI classification, 70.05% of all adults were forecast to be ‘pre-obese’ (i.e., have BMIs 23 to 24.9) by 2040 (81.23% of men and 59.07% of women) and 24.88% to be ‘normal’.

Conclusions We explored the possibility of applying and expanding on the concept of microsimulation in the field of healthcare by combining data sources available in Korea. ~~In future studies, it is necessary to develop a microsimulation model suitable for Korea’s domestic situation, and it is necessary to evaluate the effectiveness of special health policies by applying various prediction scenarios to the basic model. and found that more than half of the adults in this study population will be pre-obese, and the proportions of “obesity” and~~

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3 51 “normal” will decrease compared with those in 2012. The results of our study will aid in
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5 52 devising healthy strategies and spreading public awareness for preventing this condition.
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54 **Strengths and limitations of this study**

- 12 55 • To the best of our knowledge, this is the first study to use a microsimulation model to
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14 56 predict future obesity prevalence in Korea considering the change in population structure
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17 57 (macro level) as well as individual health behavior components (micro level).
18
19 58 • ~~The results of our study aid has the greatest significance in exploring the possibility of~~
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21 59 ~~applying and expanding the concept of microsimulation in the field of healthcare by~~
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24 60 ~~combining data sources available in Korea.~~ suggesting additional and wider-ranging
25
26 61 strategies for obesity prevention by considering sex and age group in the formulation of
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28 62 the ‘National Health Promotion Comprehensive Plan’.
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31 63 • Although a representative data source was used in this study, the prevalence of obesity
32
33 64 may be underestimated because it is based on a self-reported BMI value.
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35 65 • ~~The estimated BMI value differs from the Korea Health Statistics, which is based on the~~
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37 66 ~~data measured by actual measurement.~~
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40 67 • ~~There is a limitation that it does not accurately reflect the domestic situation because it~~
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42 68 ~~borrow a micro-simulation model developed abroad.~~ This study uses a micro-simulation
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44 69 model developed abroad, and hence, may not reflect the domestic situations accurately.
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47 70 • Another limitation is that we assumed the attributes of 19-year-old individuals to remain
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49 71 similar each year.
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74 BACKGROUND

75 The prevalence of overweight and obesity has increased markedly over the past 3 decades,
76 and concerns about health risks associated with obesity have become almost universal.[1]

77 The increasing rate of obesity is a growing public health concern not only in Western
78 countries but also in South Korea.[2] From the 1990s through the beginning of the new
79 millennium, the prevalence of adult and child obesity has increased rapidly and continues to
80 rise steadily in parallel with rapid social and economic development.[3]

81 Obesity is not only a major public health problem in itself, but also a factor in the
82 development of many chronic diseases; hence, it constitutes a strain on individuals and health
83 systems worldwide. ~~In the Global Burden of Disease Study,[4] globally in 2017, a high body-~~
84 ~~mass index (BMI) accounted for 4.72 million deaths and 148.0 million disability-adjusted-~~
85 ~~life-years.~~ It is associated with an increased risk of many disorders, including diabetes,
86 hypertension, dyslipidemia, heart disease, stroke, sleep apnea, early death, and cancer.[4-8]
87 Moreover, obesity among older people increases the risk of knee osteoarthritis[9] and reduces
88 functional capacity and quality of life.[10-13] The prevalence of these conditions rises in
89 ~~proportion to the increase in obesity[14-17] commensurate with increased obesity and is~~
90 ~~associated with significant morbidity, higher risks of mortality, and increased economic costs~~
91 ~~for both individuals and the society at large.[18] A study of data from the National Health~~
92 ~~Insurance Service in Korea found that the socioeconomic cost of obesity in 2016 was~~
93 ~~approximately 9,665.32 million US dollars.[19]~~

94 Meanwhile, with respect to worldwide comparisons, whether cutoff points for
95 overweight and obesity should be lower for Asians than for another ethnic groups remains
96 debatable.[20] The World Health Organization has proposed BMIs of 18.5–22.9 kg/m² as
97 optimal, 23–24.9 kg/m² as overweight, 25–29.9 kg/m² as moderate obesity, and ≥ 30 kg/m²
98 as severe obesity for Asians.[21] ~~However, it is more important to determine particular BMI-~~

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3 99 ~~values that increase the likelihood of developing particular chronic disease, depending on the~~
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6 100 ~~sex and age of the individual.~~ The Korean Society of Obesity, which was established to
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8 101 improve obesity management through research and education, revised its clinical practical
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10 102 guidelines for the prevention and treatment of obesity in 2018. The new guidelines renamed
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12 103 the “overweight” category to "pre-obese", and divided obesity into 3 categories, thereby
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14 104 aiming to highlight the risk of obesity instead of promoting the term "overweight." The most
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16 105 recent guidance is based in part on data of 84,690,131 Korean adults extracted from the
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18 106 Korean National Health Insurance Service Health Checkup Database between 2006 and 2015.
19
20 107 By including the entire population registered in the National Health Insurance Service
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22 108 Database, they calculated the first and second cutoff points corresponding to the increased
23
24 109 risk of any of the 3 accompanying diseases (type 2 diabetes, hypertension, and dyslipidemia)
25
26 110 ~~The first cutoff BMI level was 23 kg/m², and the second cutoff BMI level was The first and~~
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28 111 ~~second BMI cutoff levels were reported to be 23 kg/m² and 25 kg/m², respectively,~~
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31 112 suggesting the necessity of obesity criteria that accurately reflect the risk of chronic disease
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33 113 among Koreans.[22,23]

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37 114 ~~A study of data from the National Health Insurance Service in Korea found that the~~
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39 115 ~~socioeconomic cost of obesity in 2016 was approximately 9,665.32 million US dollars;~~
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41 116 ~~medical expenses accounted for 51.3% of this amount, followed by decreasing productivity~~
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43 117 ~~(20.5%), productivity loss (13.1%), early mortality (10.0%), care costs (4.3%), and~~
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45 118 ~~transportation costs (0.8%).[24] Several studies on the long-term trends of obesity prevalence~~
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47 119 ~~in South Korea found that obesity is increasing in men but not in women.[25-27]~~ Although
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49 120 numerous investigators in other countries have attempted to predict the future prevalence of
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51 121 obesity, only one such study by Inkyung Baik was recently performed in South Korea.[2]
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53 122 More recent trends still need to be investigated through predictive studies, and the accurate
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55 123 prediction of obesity prevalence remains an important public health-related goal in the
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3 124 country. To efficiently establish and execute an effective healthcare policy, which would
4
5 125 require a large budget, it is necessary to select future targets for policy interventions (such as
6
7 126 high-risk groups) to predict healthcare needs and prevent budget waste.

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10 127 Past prediction models incorporated a country's entire population; as such,
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12 128 macroscopic inferences based on average projections for the future society were generalized.
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14 129 However, when establishing a healthcare policy, it is necessary to estimate the future disease
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16 130 burden and medical needs of the entire population based on future projections that reflect
17
18 131 individual characteristics because a real-world understanding of factors that are influenced by
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20 132 policies or institutions is required. Individuals are independent entities with different
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22 133 characteristics and needs that govern their future decisions and behaviors. By applying these
23
24 134 needs, health-related projections can be modeled to reflect health risk factors such as sex,
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26 135 age, life cycle activities, smoking, etc., and the effects of policy interventions can be
27
28 136 quantified.[24] In this regard, we aimed to predict the prevalence of obesity in Korea by
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30 137 using microsimulation, which is optimal for considering individual properties.

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33 138 Microsimulation is a modeling technique, which typically uses individual microunits,
34
35 139 each with its own set of properties, to simulate downstream events based on the probability of
36
37 140 transition between predefined states and their changes over time. When used in medicine,
38
39 141 microsimulation can be particularly powerful because it preserves the patterns of previous
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41 142 behaviors and conditions, and allows for a clearer representation and understanding of how
42
43 143 various processes affect the total outcome of the population over time.[25]~~In other words,~~
44
45 144 ~~microsimulation can predict the burden of disease by modeling various health risk factors that~~
46
47 145 ~~occur during an individual's lifetime.~~ Given macro-effects such as changes in population
48
49 146 structures in the forecasting model, microsimulation is very useful as it can estimate both
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51 147 disease burdens and medical needs across the country.[24] ~~Collecting individual events from~~
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53 148 ~~within a population that has varying attributes can be used to predict and plan outcomes (such~~
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3 149 ~~as incidence, prevalence, and cost), and can also be used to assess the clinical and cost~~
4
5 150 ~~effectiveness of alternative health interventions.~~[29] Microsimulation modeling is particularly
6
7 151 useful for studying BMI trends because it can simultaneously explain population dynamics
8
9 152 such as aging, ~~migration~~, and mortality. Additionally, the longitudinal framework of these
10
11 153 models allows for interpreting a person's change in BMI as it is affected by factors such as a
12
13 154 person's physical activity and behavior, and thus, acts as a contributing factor for other
14
15 155 diseases.[26] However, while microsimulation models have been steadily evolving across
16
17 156 health- and economy-related fields in many European countries,[27] they are yet to be
18
19 157 actively utilized in South Korea (especially for healthcare).

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24 158 Obesity prevalence and trend estimates provide important information for research,
25
26 159 policy, and intervention.[28] ~~As mentioned above, it is necessary to estimate the magnitude~~
27
28 160 ~~of obesity because it has been identified as a risk factor for various chronic diseases.~~ Because
29
30 161 health forecasting predicts disease episodes and portends future events, it facilitates
31
32 162 healthcare strategies by promoting the setting of goals to reduce obesity, establish health
33
34 163 promotion interventions, and optimize resource allocation.[29] Obesity trends may also be
35
36 164 used to urge governments to implement preventative approaches for reducing obesity.[30]
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38 165 Based on the above findings, we performed this study to project the future trends in obesity
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40 166 prevalence in South Korea up to the year 2040.
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167

168 **METHODS**

169 **Model**

50
51 170 We used the Population Health Model (POHEM)-BMI to estimate the prevalence of
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53 171 obesity among adults 19 years and older in South Korea from 2012 through 2040. In brief,
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55 172 POHEM is a time-continuous, population-based, dynamic microsimulation model with
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57 173 individual underlying units of analysis used worldwide. Dynamic microsimulation, in the
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3 174 context of social science and population health, is a simulation of individuals (i.e., micro-
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5 175 level) and their behaviors, statuses, and actions (dynamics) over time.[31] These are modeled
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8 176 as desired using multiple sources of empirical data, including cross-sectional surveys,
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10 177 administrative databases, vital statistics, and census data.[32]
11
12 178 Through dynamic simulation, POHEM creates a population and ages it, one person at a time,
13
14 179 until death.[33] The model dynamically simulates an individual's disease state, risk factors,
15
16 180 and health determinants to describe and plan health outcomes.[32] POHEM is accessible
17
18 181 because it wants the general process to be constant across the country's population, with the
19
20 182 exception of variables unique to each country, such as marriage and mortality. The POHEM
21
22 183 models include cardiovascular disease, various cancers, osteoarthritis, physical activity, and
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24 184 neurological events. The model used in this study was the POHEM-BMI; the performance of
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26 185 each prediction step is shown in Figure 1.
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30 186 **Base population**

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33 187 To create the base population for the POHEM-BMI model, we used the 2011–2012 Korea
34
35 188 Health Panel survey and the resident registration-based population statistics. The base
36
37 189 population for POHEM-BMI (n=39,842,730), reflected the Korean population. Each Korean
38
39 190 respondent 19 years of age and older (n=11,501) in 2012 was replicated using their survey-
40
41 191 recorded weights to generate a simulated cohort of approximately 39,842,730 individuals.
42
43 192 Korea Health Panel survey data are nationally representative, and incorporate health status,
44
45 193 chronic diseases, health risk behaviors, and socio-demographic characteristics. Among them,
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47 194 we extracted sex, age, current smoking status, physical activity, and the previous and current
48
49 195 years' BMI values; these variables were required for the predictive equation. We then used a
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51 196 multiple linear regression model to estimate the BMI value using the extracted independent
52
53 197 variables as predictors. The POHEM-BMI model is auto-regressive and includes previous
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55 198 BMI values as a main explanatory variable.[26] For comparison with other international
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199 studies using this model, the variable composition was the same, but the variable definition
200 was not. The definition of variables was consistent with the definition of indicators in the
201 Korea Health Statistics. A current smoker was an individual who reported smoking 'every
202 day' or 'sometimes'. Practicing physical activity was defined as performing either intense
203 physical activity for at least 10 continuous minutes a day, 20 minutes total per day, 3 days a
204 week during the preceding week, or moderate physical activity for at least 30 minutes a day,
205 5 days a week during the preceding week. [Height and weight, which are components of BMI,](#)
206 [were based on self-reported data.](#)

207 **Simulation: Annual updates and risk transition**

208 The study population was updated by aging each person by 1 year and changing the total
209 population size based on population statistics, population projections, and complete life tables
210 categorized by sex and age from Korean Statistics. For population projections, we assumed a
211 medium growth scenario in terms of birth rate, life expectancy, and international migration.
212 Each person's BMI was updated annually by applying a predictive equation that incorporates
213 his/her own characteristics. The transition probability for each stochastic characteristic was
214 calculated based on a generalized linear model.

215 We assumed that the current individual behavioral patterns persisted, and no new
216 factors arose to prevent obesity, like the original POHEM-BMI. We also assumed that the
217 attributes of 19-year-old individuals, which were entered annually, remained similar each
218 year.

219 **Model validation and calibration**

220 We established the model's validity by comparing the projected BMI median
221 obtained from the prediction model to estimates obtained from the Korea Health Panel
222 survey. We set the calibration cutoff point to 5% and adjusted the model by comparing the
223 difference between the median BMI estimates observed from the Korea Health Panel survey

224 and the values derived from the prediction model categorized by sex and age. We analyzed
 225 the BMIs of each group by comparing the 2016 data available from the Korea Health Panel
 226 with the most recent data. We accepted a difference of less than 5% overall in the sex- and
 227 age-categorized groups. Finally, we adjusted the demographics of the 2040 population so that
 228 the predictions were within a 5% margin of error. In this study, all necessary data for model
 229 building and projection were obtained from publicly available data and does not include any
 230 identifiable personal information. Hence, no ethical approval was required, [in addition to the
 231 ethical and governance approvals granted by the Korea Institute for Health and Social Affairs
 232 \(KIHASA\), which conducts the Korea Health Panel Survey](#). All participants gave written
 233 informed consent before they completed the survey.

234 **Projection**

235 The model projected the BMI of each person from 2017 to 2040. Based on demographic
 236 characteristics, the projections were then aggregated by year for each of the predefined
 237 subgroups. The various trends observed in the Korean population data were used to generate
 238 algorithms that were applied to future projections.

239 **Model outputs**

240 The BMI distributions were calculated overall and by sex. Individuals with a BMI ≥ 25
 241 kg/m² were obese according to the Guidelines for the Management of Obesity in Korea,
 242 which is not the internationally accepted standard (Table 1). All analyses in this study were
 243 performed using STATA version 13 (StataCorp LLC, College Station, TX, USA).

244

245 **Table 1** BMI classification of South Korea

Classification	Body mass index (kg/m ²)
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Underweight	< 18.5
Normal	18.5 – 22.9
Pre-obese	23 – 24.9
Obese class I	25 – 29.9
Obese class II	30 – 34.9
Obese class III	≥ 35

246

247 **Patient and public involvement**

248 No patient involved

249

250 **RESULTS**

251 We compared the total number of the individuals and their characteristics in the
 252 initial 2012 population to those in the projected 2040 population (Table 2). There were
 253 39,842,730 adults who were 19 years of age or older in 2012 and 43,818,808 in 2040. The
 254 male: female ratio was nearly 1:1 in both 2012 and 2040. Rapid aging of the Korean
 255 population was clearly observed when comparing the 2 populations. The average age of
 256 adults was expected to increase by 10.9 years (from 45.69 years in 2012 to 56.59 years in
 257 2040 [from 44.57 to 55.54 years among men and 46.77 to 57.63 years among women]). In
 258 2012, the proportion of young people (those in the 19–39 and 40–64-year age groups
 259 combined) accounted for approximately 85.54% of the adult population, while the proportion
 260 of individuals aged 65 years and older was relatively low at approximately 14%. However,
 261 the age group structure in South Korea 28 years later (2040) is predicted to be quite different,
 262 as the proportion of individuals 19–64 years (i.e., the working age population) was only

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4 263 60.95% of the adult population, while the proportion of the elderly population (≥ 65 years)

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7 264 was estimated to be almost 40% of the total adult population.

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266 **Table 2** Comparison of number of people, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>						<i>Projected population (2040)</i>					
	Men		Women		Total		Men		Women		Total	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
Number of people	19,709,628		20,133,102		39,842,730		21,717,128		22,101,680		43,818,808	
Age (mean±s.d.)	44.57±15.60		46.77±16.92		45.69±16.31		55.54±18.60		57.63±19.33		56.59±19.00	
19-39	7,985,737	40.52%	7,505,824	37.29%	15,491,561	38.88%	4,873,740	22.45%	4,588,867	20.76%	9,462,607	21.60%
40-64	9,360,489	47.49%	9,230,871	45.85%	18,591,360	46.66%	8,896,886	40.97%	8,349,634	37.78%	17,246,520	39.35%
65 and above	2,363,402	11.98%	3,396,407	16.87%	5,759,809	14.45%	7,946,502	36.59%	9,163,179	41.45%	17,109,681	39.05%

Smoker	8,879,03	45.05	450,946	2.24%	9,329,983	23.42						
	7	%				%						
Physical activity	5,199,27	26.38	3,103,03	15.41	8,302,309	20.84						
	3	%	6	%		%						

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269 There was no significant difference between the median BMIs in 2012 and 2040; however, according to the BMI classification in South Korea,
 270 approximately 41.48% of the adult population was 'normal' in 2012, whereas only 24.88% of the population was predicted to be the same in
 271 2040. (see Table 3) On the other hand, the 'pre-obese' group was expected to account for approximately 70% of the total adult population.

272 **Table 3** Comparison of number of people, by BMI classification, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>						<i>Projected population (2040)</i>					
	Men		Women		Total		Men		Women		Total	
	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)	Number	(Percentage)
BMI (median)	23.59		22.41		23.04		23.97		23.17		23.55	
Number of people by BMI classification												
Underweight	840,251	(4.26)	2,368,051	(11.76)	3,208,302	(8.05)	98,954	(0.46)	152,500	(0.69)	251,454	(0.57)
Normal	7,414,311	(37.62)	9,114,015	(45.27)	16,528,326	(41.48)	2,228,567	(10.26)	8,671,481	(39.23)	10,900,048	(24.88)
Pre-obese	5,264,861	(26.71)	4,207,675	(20.90)	-	(23.77)	17,641,666	(81.23)	13,055,483	(59.08)	30,697,158	(70.05)

	6		3		9,472,53)	8		2	7)	0	
					9							
Obese class–	5,867,36	(29.77)	4,046,60	(20.10)	-	(24.88)	1,712,332	(7.88)	221,829	(1.00)	1,934,161	(4.41)
I	9		7		9,913,97))		
					6							
Obese class–	318,297	(-1.61)	—	(-1.61)	—	(-1.61)	—33,455	(0.15)	388	(0.00)	—33,843	(0.08)
II			324,205		642,502)		
Obese class–	—4,534	(-0.02)	—	(-0.36)	—	(0.19)	—2,152	(0.01)	—0	(0.00)	—2,152	(0.00)
III			72,551		77,085)		

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3 275 The model was well calibrated in both the initial population and from 2017 to 2040.
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5 276 Differences in each of the variables estimated between 2013 and 2016, which were derived
6
7 277 from the Korea Health Panel data, were within the 5% range only when using the predictive
8
9 278 model. Additionally, when compared to the population structure for 2040 (the final year) as
10
11 279 predicted by Statistics Korea, the total population, gender, and age-specific ratio were similar.

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14 280 Figure 2 shows the median predicted BMIs between 2017 and 2040. Each median
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16 281 BMI value from 2013 to 2016 was estimated from the Korea Health Panel survey. The
17
18 282 median BMI for the entire adult population is predicted to increase very slightly from 23.23
19
20 283 kg/m² in 2018 to 23.53 kg/m² in 2036 and is expected to remain steady thereafter. The
21
22 284 predicted median BMI trends are similar for men; the median BMI in adult men was
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24 285 projected to increase only slightly, from 23.74 kg/m² in 2018 to 23.95 kg/m² in 2036 and then
25
26 286 almost plateau thereafter. However, women were expected to experience a relatively steep
27
28 287 rise compared to that of men; the median BMI in adult women was projected to increase from
29
30 288 22.66 kg/m² in 2018 to 23.17 kg/m² in 2040.

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35 290 The BMI distributions for men and women from 2012 to 2040 are shown in Figure 3.
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37 291 [There was no significant difference between the median BMIs in 2012 and 2040, but the](#)
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39 292 [results according to the BMI classifications showed large changes.](#) The proportions of ‘pre-
40
41 293 obese’ individuals in both sexes are predicted to increase dramatically over time, while the
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43 294 proportions of individuals who are classified as ‘normal’ and ‘obese’ will gradually decrease.
44
45 295 As of 2025, 52.35% of all male adults were expected to be pre-obese, with that proportion
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47 296 expected to be close to 81.23% by 2040. Moreover, 53.24% of all women were expected to
48
49 297 be ‘pre-obese’ by 2035, with the proportion rising to almost 59.07% by 2040.

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53 299 [According to the BMI classification by age group, in South Korea, in 2012, about](#)
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300 20.36% of the population aged 19-39 were 'pre-obese', but in 2040, it increased to 39.59%,
 301 almost double. The proportion of the 'normal' population was almost the same in 2012 and
 302 2040, and the 'obese class I' decreased by nearly half. However, in the population aged 40
 303 to 64 and over 65, the proportion of 'pre-obese' increased almost three times in 2040
 304 compared to that in 2012, and the proportion of 'normal' decreased to less than 20% (Table
 305 3).

306

307 **Table 3** Comparison of number of people, by BMI classification, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>			<i>Projected population (2040)</i>		
	19-39	40-64	65-	19-39	40-64	65-
Number of people	15,491,561	18,591,360	5,759,809	9,462,607	17,246,520	17,109,681
BMI (median)%	22.37	23.52	23.02	23.07	23.64	23.58
Distribution of people by BMI classification						
Underweight %	11.76	5.10	7.60	2.66	0.00	0.00
Normal %	45.66	37.81	42.12	45.68	19.89	18.40
Pre-obese %	20.36	26.51	24.10	39.59	76.60	80.31
Obese class I %	20.67	28.40	24.85	11.70	3.51	1.29
Obese class II %	1.51	1.79	1.30	0.36	0.00	0.00
Obese class III %	0.03	0.38	0.02	0.02	0.00	0.00

308 DISCUSSION

309 The purpose of this study was to predict the prevalence of obesity in South Korea in
310 the year 2040 using a microsimulation model. In this study, we strove to predict future adult
311 obesity rates in South Korea using the POHEM-BMI, which was developed by Statistics
312 Canada. Summarizing the predicted results, the median BMI of South Korea's adult
313 population aged 19 years and older was expected to be 23.55 in 2040, while the percentage of
314 'pre-obese' individuals was expected to increase over time. While it is encouraging that the
315 proportion of 'obese' people (i.e., those with BMIs ≥ 25 kg/m²) in 2040 is predicted to be
316 much lower than that in 2012, it is discouraging that the proportion of 'normal' individuals is
317 also markedly lower. Most notably, the pre-obesity rate is predicted to rise dramatically. In
318 addition to the sex and age variables, our model includes only smoking and physical activity
319 as health-related behaviors. The distributions of these factors were assumed to remain equal
320 across the years; hence, our data show that maintaining smoking and physical activity rates at
321 2012 levels among adults will lead to a sharp increase in the 'pre-obese' population by 2040.

322 To the best of our knowledge, the only other study that predicted future obesity rates
323 among South Korean adults was the investigation by Baik.[2] That study explored factors
324 affecting adult as well as abdominal obesity, and constructed forecasting models to predict
325 obesity prevalence rates in 2020 and 2030 using the Korea National Health and Nutritional
326 Examination Survey (KNHANES). The prevalence rates of obesity among men and women
327 in that study were predicted to be 47% and 32%, respectively, in 2020 and 62% and 37%,
328 respectively, in 2030; these data were inconsistent with our results. [The differences in
329 prediction results appeared to be caused by the different secondary sources and prediction
330 models in the two studies. First, in Baik's study, a prediction model was constructed by
331 applying a linear regression model and an autoregressive integrated moving average model
332 using the KNHANES data. The dependent variable in the prediction model was BMI, and the](#)

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3 333 independent variables included the survey year, age, marital status, job status, income status,
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5 334 smoking, alcohol consumption, sleep duration, psychological factors, dietary intake, and
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7 335 fertility rate. In contrast, in this study, the Korea Health Panel data was used as the data
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9 336 source, and BMI was predicted by performing microsimulation with sex, age, smoking,
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11 337 physical activity, and previous years' BMIs as independent variables. Therefore, the method
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13 338 of measurement of the dependent variable, BMI differs between the studies; unlike the
14
15 339 KNHANES, which contains body-measured height and weight information, the Korea Health
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17 340 Panel (although this is a representative data source) generates data based on self-reported by
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19 341 respondents, which may underestimate obesity. ~~The differences appeared to be caused by the~~
20
21 342 ~~different secondary sources used in the 2 studies, as well as the different independent~~
22
23 343 ~~variables and prediction methodologies. In particular, Inevitably, the obesity rate in the initial~~
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25 344 population according to the KNHANES tended to be higher; as such, a higher initial
26
27 345 prevalence rate would lead to a higher projection.[34] ~~Most importantly, Baik's study did not~~
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29 346 ~~consider the preceding year's BMI, which was a major independent variable in our study; this~~
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31 347 ~~may be a major explanation for the differences in findings between the 2 studies.~~

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33 348 We also tried to compare the results from this study with the predicted estimate by
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35 349 country, but few studies have empirically predicted the prevalence of obesity in the future
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37 350 using simulation models. One study compiled nationally-representative data from various
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39 351 sources and predicted the future prevalence of overweight and obesity in Indian adults aged
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41 352 20-69 years will reach 30.5% and 9.5% among men, 27.4% and 13.9% among women,
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43 353 respectively, by 2040.[35] According to a study that estimated the prevalence of obesity in
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45 354 the future through regression modeling, 42% of Americans were expected to be obese by
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47 355 2030.[36] Similarly, a study that predicted the prevalence of obesity in Australian adults by
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49 356 2025 using a multiple linear regression model predicted that 83% of male adults over the age
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51 357 of 20 and 75% of female adults would be overweight or obese.[37] In all three countries,
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3 358 India, the United States, and Australia, overweight and obesity were defined according to the
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5 359 classifications defined by the WHO, and much higher values were found than those in Korea.
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8 360 We also compared our results to those predicted in Canada using the same model, and 59% of
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10 361 the adult Canadian population was predicted to be 'overweight or obese' by 2030.

11
12 362 This study defined obesity by applying the BMI classification system according to
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14 363 2018 Korean Society for the Study of Obesity guideline for the management of obesity in
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16 364 Korea. It would be appropriate to use international standards for comparison; however, it is
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18 365 necessary to reflect the situation of individual countries in the management of obesity for the
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20 366 purpose of preventing and managing chronic diseases. Therefore, rather than emphasizing the
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22 367 BMI classification criteria, more research is needed to **determine** the BMI values that can
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24 368 significantly predict the occurrence of chronic diseases. In other words, it is necessary to
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26 369 continuously accumulate sufficient epidemiologic evidence for the relationship between the
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28 370 BMI and the actual risk of disease and death for Koreans, and based on such evidence, efforts
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30 371 to establish appropriate diagnostic and medical standards for Koreans are needed. In
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32 372 particular, the relationship is likely to vary by age and sex; hence, it should be considered too.
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34 373 Here, the obesity standard has been applied collectively regardless of sex and age. However,
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36 374 in order to deviate from a uniform approach to obesity, gender- and age-based approaches are
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38 375 needed, considering the changes in hormones and body composition.

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40 376 Because health management policies including obesity management require a large
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42 377 budget, it is most important to establish cost-effective policies. The results from this study
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44 378 made it possible to determine the obese high-risk group by sex and age group, and estimate
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46 379 medical needs. As it is necessary to apply obesity standards differently according to sex and
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48 380 age group, it is difficult to set the 'National Health Promotion Comprehensive Plan' goals.
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50 381 This plan needs to suggest additional, wider-ranging goals considering the characteristics of
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52 382 each sex and age group, rather than presenting goals for obesity prevalence among adult men
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3 383 and women. In this case, the goal should be presented at an achievable level in consideration
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5 384 of future prediction patterns. Finally, systematic public health interventions, which are
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7 385 tailored to individual characteristics need to be established.
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10 386 Findings from this study should be interpreted with consideration of several
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12 387 limitations. First, since a microsimulation model for predicting obesity prevalence has not
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14 388 been developed in this country, we borrowed the model developed by Statistics Canada, and
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16 389 it may not fit the domestic situation; nonetheless, we defined each variable in the predictive
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18 390 equation according to the operational definition in Korea Health Statistics. However, if the
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20 391 model is more suited to the domestic situation, besides sex, age, smoking, physical activity,
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22 392 and previous year's BMI value, various factors related to BMI may be added to the predictors
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24 393 of BMI. However, in this study, as we faithfully followed the existing model and explored the
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26 394 possibility of domestic application, the process of constructing a prediction equation was
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28 395 omitted. Therefore, not only is the definition of obesity different, but the predictors of BMI
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30 396 include only sex, age, smoking, physical activity, and preceding year's BMI values. In the
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32 397 future, research to develop a new model of microsimulation in the field of healthcare for
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34 398 domestic conditions will be very valuable. In this process, it is necessary to consider practical
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36 399 suitability and efficiency in selecting basic data, module-specific behavioral equations, and
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38 400 variables for use in the model. Second, we had limited data sources. There is a difference
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40 401 between the current prevalence of obesity calculated from the Korea Health Panel data used
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42 402 in this study and the Korea Health Statistics using the KNHANES. As of 2011, the
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44 403 prevalence of adult obesity in Korea Health Statistics was 31.9%, and the prevalence of adult
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46 404 obesity calculated by the Korea Health Panel data was 23.7%, a difference of 8.2%.[38]
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48 405 Unlike the Korea Health Statistics, which contains body-measured height and weight
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50 406 information, the Korea Health Panel (although this is a representative data source) generates
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52 407 data based on self-reported by respondents, which may underestimate obesity. As mentioned
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3 408 earlier in the difference between the results of Baik's study, this difference originated from
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5 409 the method of measuring BMI in the two data sources. However, in the POHEM-BMI model
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7 410 used in this study, the BMI of the previous year was regarded as the main explanatory
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9 411 variable, and therefore, the Korea Health panel data that followed the same participants once
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11 412 a year was inevitably used. In addition, the original POHEM-BMI model includes the process
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13 413 of converting self-reported BMI into a measured BMI, but we omitted this due to limitations
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15 414 of the data source. Third, we assumed that the attributes of 19-year-old individuals entered
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17 415 each year remain at a similar level each year. This means that the individual attributes of 19-
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19 416 year-old adults are the same for 29 years from 2012 to 2040; thus, it can be considered
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21 417 somewhat less realistic. In future studies, it is expected that more meaningful and realistic
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23 418 results will be derived if the model is constructed by reflecting the trend of changes in the
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25 419 attributes of the 19-year-old population and updating it according to the year.

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27 420 Nevertheless, our study is the first to examine the possibility of using
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29 421 microsimulation to predict future BMI medians in South Korea. Additionally, the BMI of the
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31 422 future adult population was predicted after considering the change in population structure at
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33 423 the macro level as well as individual health behavior components at the micro level.

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36 37 425 **CONCLUSION**

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39 426 The key finding of this study is that by 2040, 70.05% of Korean adults are predicted
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41 427 to be pre-obese. Utilizing data sources available in Korea, the possibility of applying and
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43 428 expanding on the concept of microsimulation was explored. In future studies, a model
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45 429 suitable for South Korea needs to be developed, and the effectiveness of specific health
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47 430 policies ought to be assessed by applying various relevant scenarios to the basic forecasting
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49 431 model.

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433 **Abbreviations**

434 BMI: body mass index; KNHANES: Korea National Health and Nutritional
435 Examination Survey, POHEM: Population Health Model

436 **Authors' Contributions**

437 YS (the first author) designed the study, analyzed, and interpreted the data, and wrote
438 the paper. YE participated in the statistical analysis. DS aided in the interpretation of the data
439 and preparation of the manuscript. SJ (the corresponding author) directed this study. All
440 authors read and approved the final version of the manuscript.

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444 The funding agency had no role in the study design, analysis and interpretation of the data, or
445 the preparation of the manuscript.

446 **Competing Interests**

447 The authors declare that they have no competing interests.

448 **Ethics approval**

449 This study used publicly available data of Korea Health Panel Survey 2011-2012
450 from the Korea Institute for Health and Social Affairs and the National Health Insurance,
451 population statistics based on resident registration, population projections, complete life
452 tables and future mortality rates from Statistics Korea. The dataset does not contain any
453 identifiable personal information. Ethical approval was given by the Institutional Review
454 Board of Korea University, Seoul, Korea (IRB No. KUIRB-2020-0018-01).

455 **Data sharing statement**

456 The Korea Health Panel Survey data used in this article is available in
457 <https://www.khp.re.kr:444/eng/data/data.do>. Detailed information on the survey design and

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3 458 data characteristics are provided at <https://www.khp.re.kr:444/eng/survey/sampling.do>.

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5 459 Population statistics, population projections, and complete life tables are available from

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For peer review only

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3 572 **Figure legends**
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5 573 **Figure 1** Summary of data sources and methods used to generate and validate projections of
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8 574 distribution of BMI categories in South Korea, 2012–2040
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10 575 **Figure 2** Population Health Model (POHEM) projections of median BMI in South Korea,
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12 576 2012–2040
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14 577 **Figure 3A** Projection of distribution of BMI, adults aged 19 years and older, South Korea,
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17 578 2012–2040
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19 579 **Figure 3B** Projection of distribution of BMI, men aged 19 years and older, South Korea,
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21 580 2012–2040
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24 581 **Figure 3C** Projection of distribution of BMI, women aged 19 years and older, South Korea,
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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	8-9
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-9
		(b) Describe any methods used to examine subgroups and interactions	-
		(c) Explain how missing data were addressed	-
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	9
		(e) Describe any sensitivity analyses	-

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10-13
		(b) Indicate number of participants with missing data for each variable of interest	14
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	10-11
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	14
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	-
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	-
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	14-15
		(b) Report category boundaries when continuous variables were categorized	14-15
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18-20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18-20
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	21

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Projecting the prevalence of obesity in South Korea through 2040: a microsimulation modeling approach

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Secondary Subject Heading:	Health policy
Keywords:	PUBLIC HEALTH, Health policy < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PREVENTIVE MEDICINE

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1 **Title: Projecting the prevalence of obesity in South Korea through 2040: a**
2 **microsimulation modeling approach**

3
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21
22 **Keywords:** Microsimulation, body mass index, obesity, Population Health Model, South
23 Korea

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25 **Word count:** 4,421

ABSTRACT

Objective To project the prevalence of obesity in 2040 among individuals 19 years and older in South Korea.

Design, setting, and participants Using the ‘Population Health Model-Body Mass Index’ (POHEM-BMI) microsimulation model, the prevalence of obesity in Korean adults 19 years and older was projected until 2040. The model integrated individual survey data from the Korea Health Panel Survey of 2011 and 2012, population statistics based on resident registration, population projections, and complete life tables categorized by sex and age. Birth rate, life expectancy, and international migration were based on a medium growth scenario. The base population of Korean adults in 2012, devised through data aggregation, was 39,842,730. The prediction equations were formulated using BMI as the dependent variable; the individual’s sex, age, smoking status, physical activity, and preceding year’s BMI were used as predictive factors.

Outcome measure BMI categorized by sex.

Results The median BMI for Korean adults in 2040 was expected to be 23.55 kg/m² (23.97 and 23.17 kg/m² for men and women, respectively). According to the Korean BMI classification, 70.05% of all adults were expected to be ‘pre-obese’ (i.e., have BMIs 23 to 24.9) by 2040 (81.23% of men and 59.07% of women) and 24.88% to be ‘normal’.

Conclusions We explored the possibility of applying and expanding on the concept of microsimulation in the field of healthcare by combining data sources available in Korea and found that more than half of the adults in this study population will be pre-obese, and the proportions of “obesity” and “normal” will decrease compared with those in 2012. The results of our study will aid in devising healthy strategies and spreading public awareness for preventing this condition.

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5 52**Strengths and limitations of this study**6
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- To the best of our knowledge, this is the first study to use a microsimulation model to predict future obesity prevalence in Korea considering the change in population structure (macro level) as well as individual health behavior components (micro level).

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- The results of our study will be beneficial in suggesting additional and wider ranging goals for obesity prevention, by taking into consideration the influence of sex and age in the formulation of the ‘National Health Plan’.

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- Although a representative data source was used in this study, the prevalence of obesity may be underestimated because it is based on a self-reported BMI value.

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- This study uses a micro-simulation model developed abroad, and hence, may not reflect the domestic situations accurately.

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- Another limitation is that we assumed the attributes of 19-year-old individuals to remain similar each year.

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67 **BACKGROUND**

68 The prevalence of overweight and obesity has increased markedly over the past 3 decades,
69 and concerns about health risks associated with obesity have become almost universal.[1]

70 The increasing rate of obesity is a growing public health concern not only in Western
71 countries but also in South Korea.[2] From the 1990s through the beginning of the new
72 millennium, the prevalence of adult and child obesity has increased rapidly and continues to
73 rise steadily in parallel with rapid social and economic development.[3]

74 Obesity, a major public health problem and a factor in the development of many
75 chronic diseases, constitutes a strain on individuals and health systems worldwide. The
76 associated disorders of obesity include diabetes, hypertension, dyslipidemia, heart disease,
77 stroke, sleep apnea, early death, and cancer.[4-8] Moreover, obesity among older people
78 increases the risk of knee osteoarthritis[9] and reduces functional capacity and quality of
79 life.[10-13] The prevalence of these conditions rises in proportion to the increase in
80 obesity[14-17] and is associated with increased economic costs for both individuals and the
81 society at large.[18] A study using the National Health Insurance Service data in Korea found
82 that the socioeconomic cost of obesity in 2016 was approximately 9,665.32 million US
83 Dollars.[19]

84 Meanwhile, with respect to worldwide comparisons, whether cutoff points for
85 overweight and obesity should be lower for Asians than for another ethnic groups remains
86 debatable.[20] The World Health Organization has proposed BMIs of 18.5–22.9, 23–24.9,
87 25–29.9, and ≥ 30 kg/m² as optimal, overweight, moderate, and severe obesity for Asians,
88 respectively.[21] The Korean Society of Obesity, which was established to improve obesity
89 management through research and education, revised its clinical practical guidelines for the
90 prevention and treatment of obesity in 2018. The new guidelines renamed the “overweight”
91 category to "pre-obese", and divided obesity into 3 categories, to highlight the risk of obesity,

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3 92 instead of promoting the term "overweight." The most recent guideline is based in part on
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5 93 data of 84,690,131 Korean adults extracted from the Korean National Health Insurance
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7 94 Service Health Checkup Database between 2006 and 2015. By including the entire
8
9 95 population registered in the National Health Insurance Service Database, they calculated the
10
11 96 first and second cutoff points corresponding to the increased risk of any of the 3
12
13 97 accompanying diseases (type 2 diabetes, hypertension, and dyslipidemia). The first (23
14
15 98 kg/m²) and second (25 kg/m²) cutoff BMI levels suggest the necessity of obesity criteria that
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17 99 accurately reflect the risk of chronic disease among Koreans.[22,23]
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21
22 100 Although numerous investigators in other countries have attempted to predict the
23
24 101 future prevalence of obesity, only one such study by Inkyung Baik was recently performed in
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26 102 South Korea.[2] More recent trends still need to be investigated through predictive studies,
27
28 103 and the accurate prediction of obesity prevalence remains an important public health-related
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30 104 goal in the country. To efficiently establish and execute an effective healthcare policy, which
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32 105 would require a large budget, it is necessary to select future targets for policy interventions
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34 106 (such as high-risk groups) to predict healthcare needs and prevent budget waste.
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37 107 Past prediction models incorporated a country's entire population; as such,
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39 108 macroscopic inferences based on average projections for the future society were generalized.
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41 109 However, when establishing a healthcare policy, it is necessary to predict the future burden of
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43 110 disease and medical needs of the entire population based on a real-world understanding of
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45 111 individual-level factors that are influenced by policies or institutions. Individuals are
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47 112 independent entities with different characteristics and needs, and health-related projections
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49 113 can be modeled to reflect these individual characteristics, including health risk factors.[24] In
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51 114 this regard, we aimed to predict the prevalence of obesity in Korea by using microsimulation,
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53 115 which is optimal for considering individual properties.
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58 116 Microsimulation, a modeling technique, typically uses individual microunits, each
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3 117 with its own set of properties, to simulate downstream events based on the probability of
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5 118 transition between predefined states and their changes over time. When used in medicine,
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7 119 microsimulation can be particularly powerful because it preserves the patterns of previous
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9 120 behaviors and conditions, and allows for a clearer representation and understanding of how
10
11 121 various processes affect the total outcome of the population over time.[25] Given macro-
12
13 122 effects such as changes in population structures in the forecasting model, microsimulation is
14
15 123 very useful as it can estimate both disease burdens and medical needs across the country.[24]
16
17 124 Microsimulation modeling is particularly useful for studying BMI trends because it can
18
19 125 simultaneously explain population dynamics such as aging and mortality.[26] However,
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21 126 while microsimulation models have been steadily evolving across health- and economy-
22
23 127 related fields in many European countries,[27] they are yet to be actively utilized in South
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25 128 Korea (especially for healthcare).

26
27 129 Obesity prevalence and trend estimates provide important information for research,
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29 130 policy, and intervention.[28] Because health forecasting predicts disease episodes and
30
31 131 portends future events, it facilitates healthcare strategies by promoting the setting of goals to
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33 132 reduce obesity, establish health promotion interventions, and optimize resource
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35 133 allocation.[29] Obesity trends may also be used to urge governments to implement
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37 134 preventative approaches for reducing obesity.[30] Based on the above findings, we performed
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39 135 this study to project the future trends in obesity prevalence in South Korea up to the year
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41 136 2040.

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50 51 138 **METHODS**

52 53 139 **Model**

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55 140 We used the Population Health Model (POHEM)-BMI[26] to estimate the prevalence
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57 141 of obesity among adults 19 years and older in South Korea from 2012 through 2040. In brief,
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3 142 POHEM is a time-continuous, population-based, dynamic microsimulation model with
4
5 143 individual underlying units of analysis used worldwide. Dynamic microsimulation, in the
6
7 144 context of social science and population health, is a simulation of individuals (i.e., micro-
8
9 145 level) and their behaviors, statuses, and actions (dynamics) over time.[31] These are modeled
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11 146 as desired using multiple sources of empirical data, including cross-sectional surveys,
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13 147 administrative databases, vital statistics, and census data.[32]
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15 148 Through dynamic simulation, POHEM creates a population and ages it, one person at a time,
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17 149 until death.[33] The model dynamically simulates an individual's disease state, risk factors,
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19 150 and health determinants to describe and plan health outcomes.[32] POHEM is accessible
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21 151 because it wants the general process to be constant across the country's population, with the
22
23 152 exception of variables unique to each country, such as marriage and mortality. The POHEM
24
25 153 models include cardiovascular disease, various cancers, osteoarthritis, physical activity, and
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27 154 neurological events. The model used in this study was the POHEM-BMI; the performance of
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29 155 each prediction step is shown in Figure 1.
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35 **Base population**

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37 157 To create the base population for the POHEM-BMI model, we used the 2011–2012 Korea
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39 158 Health Panel survey[34] and the resident registration-based population statistics.[35] The
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41 159 base population for POHEM-BMI (n=39,842,730), reflected the Korean population. Each
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43 160 Korean respondent 19 years of age and older (n=11,501) in 2012 was replicated using their
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45 161 survey-recorded weights to generate a simulated cohort of approximately 39,842,730
46
47 162 individuals. Korea Health Panel survey data are nationally representative, and incorporate
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49 163 health status, chronic diseases, health risk behaviors, and socio-demographic characteristics.
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51 164 Among them, we extracted sex, age, current smoking status, physical activity, and the
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53 165 previous and current years' BMI values; these variables were required for the predictive
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55 166 equation. We then used a multiple linear regression model to estimate the BMI value using
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3 167 the extracted independent variables as predictors. The POHEM-BMI model is auto-regressive
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5 168 and includes previous BMI values as the main explanatory variable.[26] We matched the
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8 169 composition of the variables considered as covariates in the POHEM-BMI model. We did not
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10 170 match the operational definition of the variables because we applied the Korea Health Panel
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12 171 Survey data (not the survey data obtained in Canada where the POHEM model was
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14 172 developed). The definitions of the variables in this study are consistent with the definitions of
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16 173 the indicators in the Korea Health Statistics.[36] A current smoker was an individual who
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18 174 reported smoking 'every day' or 'sometimes'. Practicing physical activity was defined as
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20 175 performing either intense physical activity for at least 10 continuous minutes a day, 20
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22 176 minutes total per day, 3 days a week during the preceding week, or moderate physical activity
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24 177 for at least 30 minutes a day, 5 days a week during the preceding week. Height and weight,
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26 178 which are components of BMI, were based on self-reported data.

179 **Simulation: Annual updates and risk transition**

180 The study population was updated by aging each person by 1 year and changing the total
181 population size based on population statistics, population projections, and complete life tables
182 categorized by sex and age from the Korean Statistics. For population projections, we
183 assumed a medium growth scenario in terms of birth rate, life expectancy, and international
184 migration. Each person's BMI was updated annually by applying a predictive equation that
185 incorporates individual's own characteristics. The transition probability for each stochastic
186 characteristic was calculated based on a generalized linear model.

187 We assumed that the current individual behavioral patterns persisted, and no new
188 factors arose to prevent obesity, like in the original POHEM-BMI. We also assumed that the
189 attributes of 19-year-old individuals, which were entered annually, remained similar each
190 year. Therefore, in this model, since each individual's smoking status and physical activity in
191 the initial population remained the same until 2040, the model predicted the BMI when the

192 adult smoking and physical activity rates in the initial year (2012) persisted until 2040.

193 **Model validation and calibration**

194 In order to establish the validity of the prediction model, we adjusted the model by
195 comparing the 2013 to 2016 median BMIs projected from the model with the 2013 to 2016
196 Korea Health Panel Survey median BMI estimates. We compared the median BMI values for
197 each sex and age group from 2013 to 2016, and accepted a difference between the median
198 BMI values in the prediction model and in the Korea Health Panel Survey to less than 5% by
199 setting the calibration cutoff point to 5%. Finally, we adjusted the demographics of the 2040
200 population so that the predictions were within the 5% margin of error. In this study, all the
201 necessary data for model building and projection were obtained from publicly available data
202 and do not include any identifiable personal information. Hence, no ethical approval was
203 required in addition to the ethical and governance approvals granted by the Korea Institute for
204 Health and Social Affairs (KIHASA), which conducts the Korea Health Panel Survey. All
205 participants gave written informed consent before they completed the survey.

206 **Projection**

207 The model, validated through calibration, projected the BMI of each person from 2017 to
208 2040. Based on the demographic characteristics, the projections were then aggregated by year
209 for each of the predefined subgroups. The various trends observed in the Korean population
210 data were used to generate algorithms that were applied to future projections.

211 **Model outputs**

212 The BMI distributions were calculated overall and by sex. Individuals with a BMI ≥ 25
213 kg/m² were regarded as obese according to the Guidelines for the Management of Obesity in
214 Korea, which is not the internationally accepted standard (Table 1). All analyses in this study
215 were performed using STATA version 13 (StataCorp LLC, College Station, TX, USA).

216

217 **Table 1** BMI classification of South Korea

Classification	Body mass index (kg/m ²)
Underweight	< 18.5
Normal	18.5 – 22.9
Pre-obese	23 – 24.9
Obese class I	25 – 29.9
Obese class II	30 – 34.9
Obese class III	≥ 35

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219 **Patient and public involvement**

220 No patient involved

221

222 **RESULTS**

223 We compared the total number of the individuals and their characteristics in the
 224 initial 2012 population to those in the projected 2040 population (Table 2). There were
 225 39,842,730 adults who were 19 years of age or older in 2012 and 43,818,808 in 2040. The
 226 male: female ratio was nearly 1:1 in both 2012 and 2040. Rapid aging of the Korean
 227 population was clearly observed when comparing the 2 populations. The mean age of adults
 228 was expected to increase by 10.9 years (from 45.69 years in 2012 to 56.59 years in 2040
 229 [from 44.57 to 55.54 years among men and 46.77 to 57.63 years among women]). In 2012,
 230 the proportion of young people (those in the 19–39 and 40–64-year age groups combined)
 231 accounted for approximately 85.54% of the adult population, while the proportion of

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3 232 individuals aged 65 years and older was relatively low at approximately 14%. However, the
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5 233 age group structure in South Korea 28 years later (2040) is predicted to be quite different, as
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7 234 the proportion of individuals 19–64 years (i.e., the working age population) was only 60.95%
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10 235 of the adult population, while the proportion of the elderly population (≥ 65 years) was
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13 236 estimated to be almost 40% of the total adult population. As of 2012, men and women
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15 237 smoking rates were 45.05% and 2.24%, respectively, and physical activity rates were 15.41%
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17 238 and 20.84%, respectively. In this study, only the BMI was updated annually by the predictive
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19 239 equation, so the adult smoking rate and physical activity rate in 2040 are the same as in the
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21 240 initial 2012 population.
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242 **Table 2** Comparison of the number of people, South Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>						<i>Projected population (2040)</i>					
	Men		Women		Total		Men		Women		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Number of people	19,709,628		20,133,102		39,842,730		21,717,128		22,101,680		43,818,808	
Age (mean±s.d.)	44.57±15.60		46.77±16.92		45.69±16.31		55.54±18.60		57.63±19.33		56.59±19.00	
19-39 years	7,985,737	40.52%	7,505,824	37.29%	15,491,561	38.88%	4,873,740	22.45%	4,588,867	20.76%	9,462,607	21.60%
40-64 years	9,360,489	47.49%	9,230,871	45.85%	18,591,360	46.66%	8,896,886	40.97%	8,349,634	37.78%	17,246,520	39.35%
65 years and above	2,363,402	11.98%	3,396,407	16.87%	5,759,809	14.45%	7,946,502	36.59%	9,163,179	41.45%	17,109,681	39.05%
Smoker	8,879,037	45.05%	450,946	2.24%	9,329,983	23.42%						
Physical activity	5,199,273	26.38%	3,103,036	15.41%	8,302,309	20.84%						

243 s.d. standard deviation

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3 245 The model was well calibrated to establish the validity. The difference in median
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5 246 BMI between that estimated from the 2013 and 2016 Korea Health Panel survey and that
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7 247 predicted by the 2013 and 2016 model was within the 5% range. Additionally, when
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9 248 compared to the population structure for 2040 (the final year) as predicted by Statistics
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11 249 Korea, the total population, gender, and age-specific ratio in the prediction model were
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13 250 similar.
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17 251 Figure 2 shows the median BMI of the adult population from 2012 when the initial
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19 252 population was generated to 2040, the final projected year. Each median BMI value from
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21 253 2013 to 2016 was estimated from the Korea Health Panel survey, and the median BMI from
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23 254 2017 to 2040 is the predicted value determined by the model. The median BMI for the entire
24
25 255 adult population is predicted to increase very slightly from 23.23 kg/m² in 2018 to 23.53
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27 256 kg/m² in 2036 and is expected to remain steady thereafter. The predicted median BMI trends
28
29 257 are similar for men; the median BMI in adult men was projected to increase only slightly,
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31 258 from 23.74 kg/m² in 2018 to 23.95 kg/m² in 2036 and then almost plateau thereafter.
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33 259 However, women were expected to experience a relatively steep rise compared to that of
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35 260 men; the median BMI in adult women was projected to increase from 22.66 kg/m² in 2018 to
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37 261 23.17 kg/m² in 2040. The model in this study, used to predict the BMI of the population, did
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39 262 not include any uncertainty parameters for the estimates.
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47 264 The BMI distributions for men and women from 2012 to 2040 are shown in Figure 3.
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49 265 There was no significant difference between the median BMIs in 2012 and 2040, but the
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51 266 results according to the BMI classifications showed large changes. The proportions of ‘pre-
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53 267 obese’ individuals in both sexes are predicted to increase dramatically over time, while the
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55 268 proportions of individuals who are classified as ‘normal’ and ‘obese’ will gradually decrease.
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57 269 As of 2025, 52.35% of all male adults were expected to be pre-obese, with that proportion
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270 expected to be close to 81.23% by 2040. Moreover, 53.24% of all women were expected to
 271 be 'pre-obese' by 2035, with the proportion rising to almost 59.07% by 2040.

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273 According to the BMI classification by age group, in South Korea, in 2012, about
 274 20.36% of the population aged 19-39 were 'pre-obese', but in 2040, it increased to 39.59%,
 275 almost double. The proportion of the 'normal' population was almost the same in 2012 and
 276 2040, and the 'obese class I' decreased by nearly half. However, in the population aged 40
 277 to 64 and over 65, the proportion of 'pre-obese' increased almost three times in 2040
 278 compared to that in 2012, and the proportion of 'normal' decreased to less than 20% (Table
 279 3).

280

281 **Table 3** Comparison of the number of people according to the BMI classification by age group, South

282 Korea, 2012 and 2040

	<i>Population at baseline (2012)</i>			<i>Projected population (2040)</i>		
	19-39 years	40-64 years	65- years	19-39 years	40-64 years	65- years
Number of people	15,491,561	18,591,360	5,759,809	9,462,607	17,246,520	17,109,681
BMI (median)	22.37	23.52	23.02	23.07	23.64	23.58
Distribution of people by BMI classification						
Underweight %	11.76	5.10	7.60	2.66	0.00	0.00
Normal %	45.66	37.81	42.12	45.68	19.89	18.40
Pre-obese %	20.36	26.51	24.10	39.59	76.60	80.31
Obese class I %	20.67	28.40	24.85	11.70	3.51	1.29
Obese class II %	1.51	1.79	1.30	0.36	0.00	0.00
Obese class III %	0.03	0.38	0.02	0.02	0.00	0.00

283 DISCUSSION

284 The purpose of this study was to predict the prevalence of obesity in South Korea in
285 the year 2040 using a microsimulation model. In this study, we strove to predict future adult
286 obesity rates in South Korea using the POHEM-BMI, which was developed by Statistics
287 Canada. Summarizing the predicted results, the median BMI of South Korea's adult
288 population aged 19 years and older was expected to be 23.55 in 2040, while the percentage of
289 'pre-obese' individuals was expected to increase over time. While it is encouraging that the
290 proportion of 'obese' people (i.e., those with BMIs ≥ 25 kg/m²) in 2040 is predicted to be
291 much lower than that in 2012, it is discouraging that the proportion of 'normal' individuals is
292 also markedly lower. Most notably, the pre-obesity rate is predicted to rise dramatically. In
293 addition to the sex and age variables, our model includes only smoking and physical activity
294 as health-related behaviors. It was assumed that the status of these health risk factors remain
295 consistent from the initial population period to the final projected year of 2040; hence, our
296 results showed that maintaining smoking and physical activity rates in 2012 among adults
297 will lead to a sharp increase in the 'pre-obese' population by 2040.

298 To the best of our knowledge, the only other study that predicted future obesity rates
299 among South Korean adults was the investigation by Baik.[2] That study explored factors
300 affecting adult as well as abdominal obesity, and constructed forecasting models to predict
301 obesity prevalence rates in 2020 and 2030 using the Korea National Health and Nutritional
302 Examination Survey (KNHANES). The prevalence rates of obesity among men and women
303 in that study were predicted to be 47% and 32%, respectively, in 2020 and 62% and 37%,
304 respectively, in 2030; these data were inconsistent with our results. The differences in
305 prediction results appeared to be caused by the different secondary sources and prediction
306 models in the two studies. First, in Baik's study, a prediction model was constructed by
307 applying a linear regression model and an autoregressive integrated moving average model

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3 308 using the KNHANES data. The dependent variable in the prediction model was BMI, and the
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5 309 independent variables included the survey year, age, marital status, job status, income status,
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7 310 smoking, alcohol consumption, sleep duration, psychological factors, dietary intake, and
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9 311 fertility rate. In contrast, in this study, the Korea Health Panel data was used as the data
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11 312 source, and BMI was predicted by performing microsimulation with sex, age, smoking,
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13 313 physical activity, and previous years' BMIs as independent variables. Therefore, the method
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15 314 of measurement of the dependent variable, BMI differs between the studies; unlike the
16
17 315 KNHANES, which contains body-measured height and weight information, the Korea Health
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19 316 Panel (although this is a representative data source) generates data based on self-reported by
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21 317 respondents, which may underestimate obesity. Inevitably, the obesity rate in the initial
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23 318 population according to the KNHANES tended to be higher; as such, a higher initial
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25 319 prevalence rate would lead to a higher projection.[37]

30 320 We also tried to compare the results from this study with the predicted estimate by
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32 321 country, but few studies have empirically predicted the prevalence of obesity in the future
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34 322 using simulation models. One study compiled nationally-representative data from various
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36 323 sources and predicted the future prevalence of overweight and obesity in Indian adults aged
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38 324 20-69 years will reach 30.5% and 9.5% among men, 27.4% and 13.9% among women,
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40 325 respectively, by 2040.[38] According to a study that estimated the prevalence of obesity in
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42 326 the future through regression modeling, 42% of Americans were expected to be obese by
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44 327 2030.[39] Similarly, a study that predicted the prevalence of obesity in Australian adults by
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46 328 2025 using a multiple linear regression model predicted that 83% of male adults over the age
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48 329 of 20 and 75% of female adults would be overweight or obese.[40] In all three countries,
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50 330 India, the United States, and Australia, overweight and obesity were defined according to the
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52 331 classifications defined by the WHO, and much higher values were found than those in Korea.
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54 332 We also compared our results to those predicted in Canada using the same model, and 59% of
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3 333 the adult Canadian population was predicted to be 'overweight or obese' by 2030.
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5 334 This study defined obesity by applying the BMI classification system according to
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7 335 2018 Korean Society for the Study of Obesity guideline for the management of obesity in
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9 336 Korea. It would be appropriate to use international standards for comparison; however, it is
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11 337 necessary to reflect the situation of individual countries in the management of obesity for the
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13 338 purpose of preventing and managing chronic diseases. Therefore, rather than emphasizing the
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15 339 BMI classification criteria, more research is needed to determine the BMI values that can
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17 340 significantly predict the occurrence of chronic diseases. In other words, it is necessary to
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19 341 continuously accumulate sufficient epidemiologic evidence for the relationship between the
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21 342 BMI and the actual risk of disease and death for Koreans, and based on such evidence, efforts
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23 343 to establish appropriate diagnostic and medical standards for Koreans are needed. In
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25 344 particular, the relationship is likely to vary by age and sex; hence, it should be considered too.
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27 345 Here, the obesity standard has been applied collectively regardless of sex and age. However,
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29 346 in order to deviate from a uniform approach to obesity, gender- and age-based approaches are
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31 347 needed, considering the changes in hormones and body composition.
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37 348 Because health management policies including obesity management require a large
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39 349 budget, it is most important to establish cost-effective policies. The results from this study
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41 350 made it possible to determine the obese high-risk group by sex and age group, and to estimate
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43 351 medical needs. As it is necessary to apply obesity standards differently according to sex and
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45 352 age group, it is difficult to set the 'National Health Plan' [41] goals. This plan needs to
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47 353 suggest additional, wider ranging goals considering the characteristics of each sex and age
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49 354 group, rather than presenting goals for obesity prevalence among adult men and women. In
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51 355 this case, the goal should be presented at an achievable level in consideration of future
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53 356 prediction patterns. Finally, systematic public health interventions, which are tailored to
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55 357 individual characteristics need to be established.
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3 358 Findings from this study should be interpreted with consideration to several limitations. First,
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5 359 since a microsimulation model for predicting obesity prevalence has not been developed in
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7 360 South Korea, we adapted the model developed by Statistics Canada, and this may not fit our
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9 361 domestic situation. If the BMI predictors are suitable for our domestic situation, that is, if
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11 362 variables that are important for predicting BMI of Koreans are constructed through empirical
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13 363 analysis or literature review, the composition of the covariates may be different from that of
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15 364 the existing POHEM-BMI model. However, in this study, since we explored the possibility of
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17 365 a domestic application of the model and carefully adapted the existing model, the process of
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19 366 constructing a prediction equation was omitted. In the future, research to develop a new
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21 367 model of microsimulation in the field of healthcare for domestic conditions will be very
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23 368 valuable. In this process, it is necessary to consider practical suitability and efficiency in
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25 369 selecting basic data, module-specific behavioral equations, and variables for use in the model.
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27 370 Second, we had limited data sources. The prevalence of obesity calculated in this study is
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29 371 different from that of the Korea Health Statistics using the KNHANES, and as of 2011, the
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31 372 prevalence of adult obesity in the Korea Health Statistics was 8.2% higher than that of the
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33 373 Korea Health Panel Survey.[42] Although the method of measuring BMI in KNHANES is
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35 374 more accurate, in the POHEM-BMI model used in this study, the BMI of the previous year
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37 375 was regarded as the main explanatory variable, and therefore, the Korea Health panel data
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39 376 that followed-up the same participants once a year was inevitably used. In addition, the
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41 377 original POHEM-BMI model includes the process of converting self-reported BMI into a
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43 378 measured BMI, but we omitted this due to limitations of the data source. Third, we assumed
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45 379 that the attributes of 19-year-old individuals entered each year remain at a similar level each
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47 380 year. This means that the individual attributes of 19-year-old adults are the same for 29 years
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49 381 from 2012 to 2040; thus, it can be considered somewhat less realistic. In future studies, it is
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51 382 expected that more meaningful and realistic results will be derived if the model is constructed
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383 by reflecting the trend of changes in the attributes of the 19-year-old population and updating
384 it according to the year.

385 Nevertheless, our study is the first to examine the possibility of using
386 microsimulation to predict future BMI medians in South Korea. Additionally, the BMI of the
387 future adult population was predicted after considering the change in population structure at
388 the macro level as well as individual health behavior components at the micro level.

389

390 **CONCLUSION**

391 The key finding of this study is that by 2040, 70.05% of Korean adults are predicted
392 to be pre-obese. Utilizing data sources available in Korea, the possibility of applying and
393 expanding on the concept of microsimulation was explored. In future studies, a model
394 suitable for South Korea needs to be developed, and the effectiveness of specific health
395 policies ought to be assessed by applying various relevant scenarios to the basic forecasting
396 model.

397

398 **Abbreviations**

399 BMI: body mass index; KNHANES: Korea National Health and Nutritional
400 Examination Survey, POHEM: Population Health Model; s.d. standard deviation

401 **Authors' contributions**

402 YS (the first author) designed the study, analyzed, and interpreted the data, and wrote
403 the paper. YE participated in the statistical analysis. DS aided in the interpretation of the data
404 and preparation of the manuscript. SJ (the corresponding author) directed this study. All
405 authors read and approved the final version of the manuscript.

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5 409 The funding agency had no role in the study design, analysis and interpretation of the data, or
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7
8 410 the preparation of the manuscript.
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10 411 **Competing Interests**

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12 412 The authors declare that they have no competing interests.
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14 413 **Ethics approval**

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17 414 This study used publicly available data of Korea Health Panel Survey 2011-2012
18
19 415 from the Korea Institute for Health and Social Affairs and the National Health Insurance,
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21 416 population statistics based on resident registration, population projections, complete life
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23 417 tables and future mortality rates from Statistics Korea. The dataset does not contain any
24
25 418 identifiable personal information. Ethical approval was given by the Institutional Review
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27 419 Board of Korea University, Seoul, Korea (IRB No. KUIRB-2020-0018-01).
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30 420 **Data sharing statement**

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33 421 The Korea Health Panel Survey data used in this article is available in
34
35 422 <https://www.khp.re.kr:444/eng/data/data.do>. Detailed information on the survey design and
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37 423 data characteristics are provided at <https://www.khp.re.kr:444/eng/survey/sampling.do>.
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39 424 Population statistics, population projections, and complete life tables are available from
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41 425 <http://kosis.kr/eng/>.
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3 542 **Figure legends**
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5 543 **Figure 1** Summary of the data sources and methods used to generate and validate the
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8 544 projections of the distribution of BMI categories in South Korea, 2012–2040
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10 545 **Figure 2** Population Health Model (POHEM) projections of median BMI in South Korea,
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12 546 2012–2040
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14 547 **Figure 3A** Projection of the distribution of BMI, adults aged 19 years and older, South
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17 548 Korea, 2012–2040
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19 549 **Figure 3B** Projection of the distribution of BMI, men aged 19 years and older, South Korea,
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24 551 **Figure 3C** Projection of the distribution of BMI, women aged 19 years and older, South
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BMI categories in South Korea, 2012-2040

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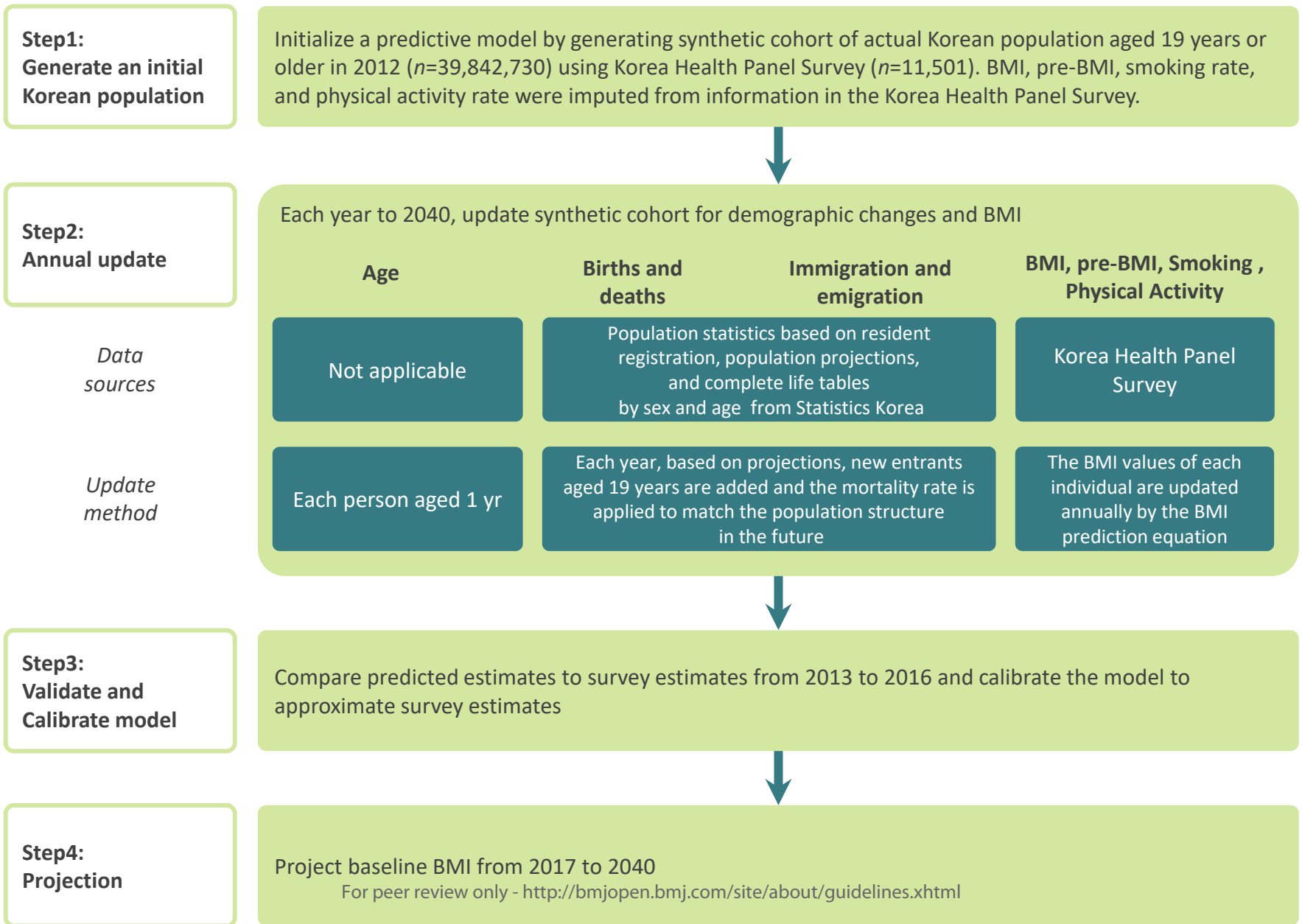
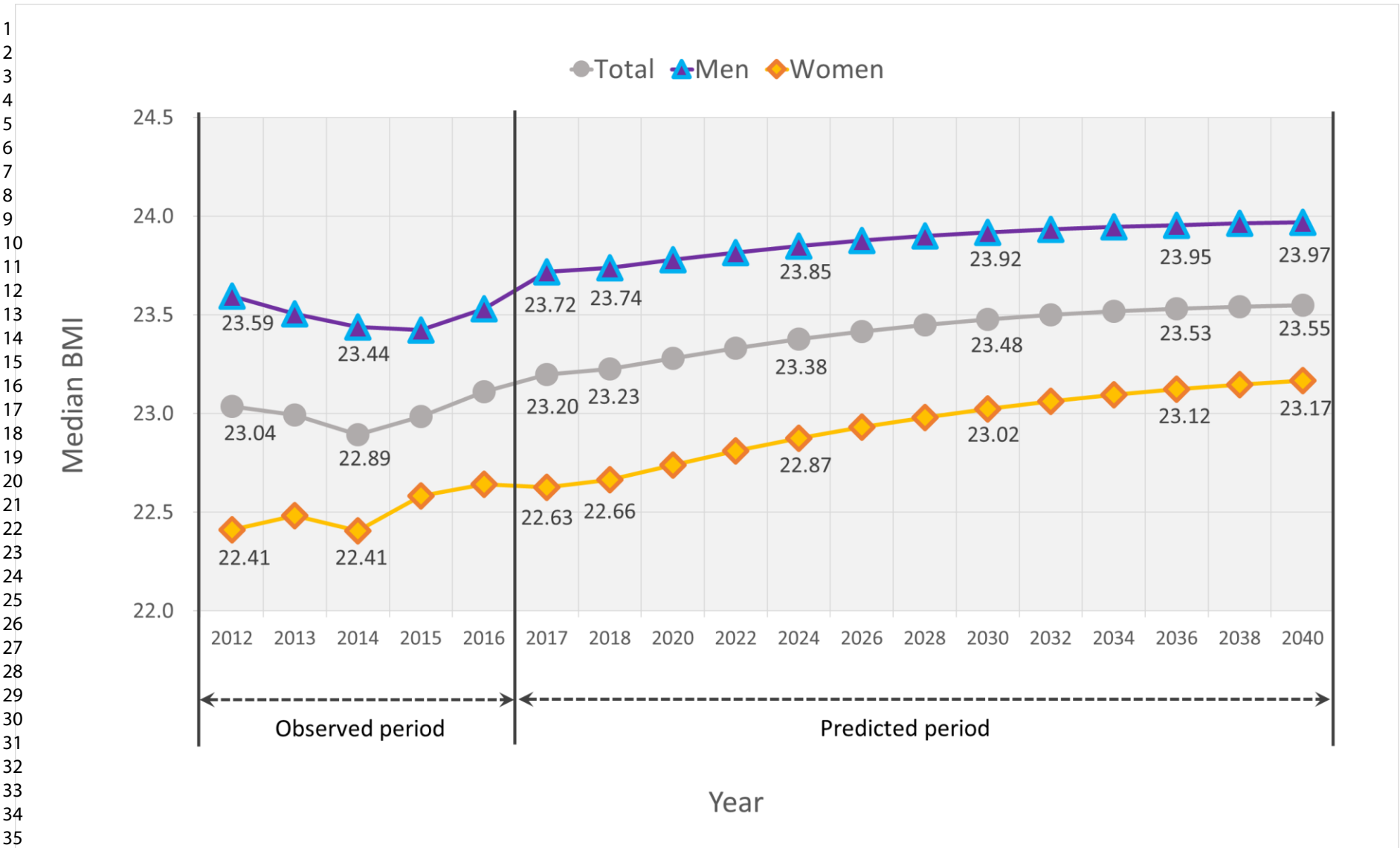
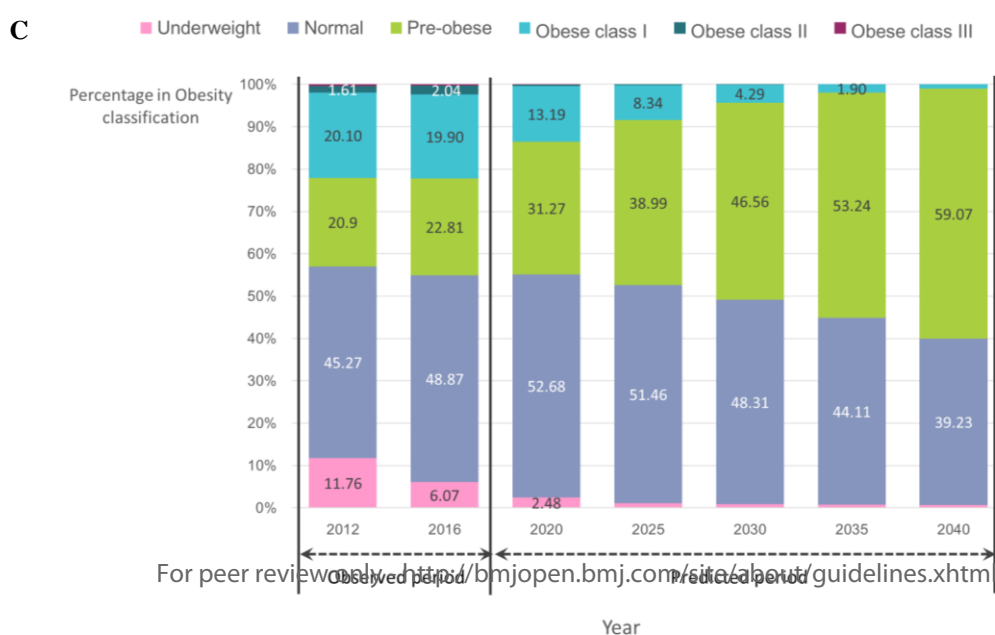
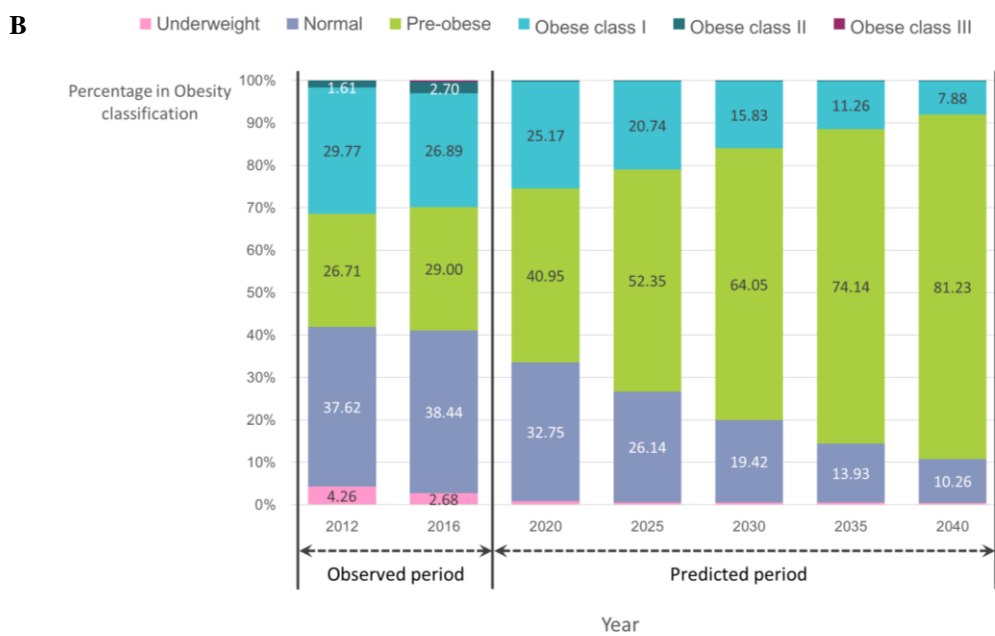
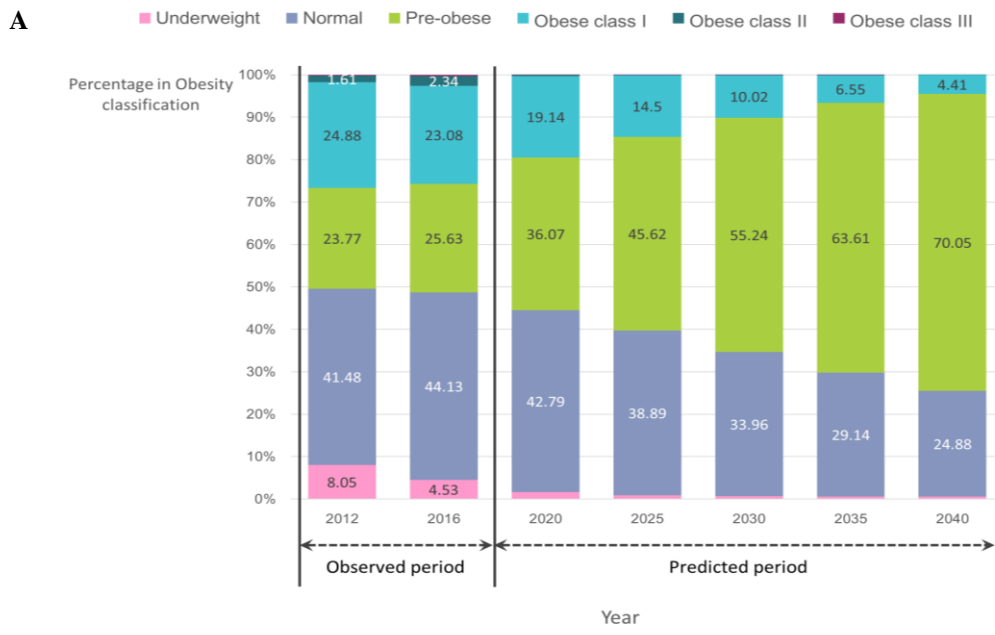


Figure 2 Population Health Model (POHEM) projections of Median BMI in South Korea, 2012-2040





STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(a) <i>Cohort study</i> —Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up <i>Case-control study</i> —Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls <i>Cross-sectional study</i> —Give the eligibility criteria, and the sources and methods of selection of participants	8-9
		(b) <i>Cohort study</i> —For matched studies, give matching criteria and number of exposed and unexposed <i>Case-control study</i> —For matched studies, give matching criteria and the number of controls per case	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-9
		(b) Describe any methods used to examine subgroups and interactions	-
		(c) Explain how missing data were addressed	-
		(d) <i>Cohort study</i> —If applicable, explain how loss to follow-up was addressed <i>Case-control study</i> —If applicable, explain how matching of cases and controls was addressed <i>Cross-sectional study</i> —If applicable, describe analytical methods taking account of sampling strategy	9
		(e) Describe any sensitivity analyses	-

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10-13
		(b) Indicate number of participants with missing data for each variable of interest	14
		(c) <i>Cohort study</i> —Summarise follow-up time (eg, average and total amount)	10-11
Outcome data	15*	<i>Cohort study</i> —Report numbers of outcome events or summary measures over time	14
		<i>Case-control study</i> —Report numbers in each exposure category, or summary measures of exposure	-
		<i>Cross-sectional study</i> —Report numbers of outcome events or summary measures	-
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	13-14
		(b) Report category boundaries when continuous variables were categorized	13-14
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-
Discussion			
Key results	18	Summarise key results with reference to study objectives	15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18-19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	15-19
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19-20

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.