Impact of salt reduction on medical expenditure for hypertension in Japan: national and subnational simulation models

Nobuo Nishi
Graduate School of Public Health,
St. Luke's International University
Chuo 104-0045, Japan
nishi.nobuo.24@slcn.ac.jp

Takehiro Sugiyama
National Institute of Global Health and Medicine, Japan Institute for Health Security
Shinjuku 162-8655, Japan
Institute of Medicine, University of Tsukuba
Tsukuba 305-8575, Japan
sugiyama.t@jihs.go.jp

Sayuri Goryoda
Graduate School of Agricultural Sciences, Yamagata University
Tsuruoka 997-8555, Japan;
goryoda@tds1.tr.yamagata-u.ac.jp

Yutaka Takahashi
School of Commerce, Senshu University
Chiyoda 101-8425, Japan;
takahasi@isc.senshu-u.ac.jp

Katsuyuki Miura
NCD Epidemiology Research Center, Shiga University of Medical Science
Otsu 520-2192, Japan;
miura@belle.shiga-med.ac.jp

Nayu Ikeda
Center for Nutritional Epidemiology and Policy Research, National Institute of Health and Nutrition, National Institutes of Biomedical Innovation, Health and Nutrition
Settsu 566-0002, Japan;
ikedan@nibn.go.jp

Keywords: Hypertension; Japan; medical expenditure; salt reduction; subnational

Funding Source: a Health and Labor Sciences Research Grant from the Ministry of Health, Labor, and Welfare of Japan (grant number: 23FA1012)

INTRODUCTION

The daily salt intake among Japanese adults has decreased, according to the National Health and Nutrition Survey (NHNS) [1,2]. However, it remains high at 9.6 g in 2024 [3], exceeding the recommendations of the World Health Organization (WHO) (< 5 g) [4] and the Dietary Reference Intakes for Japanese (< 7.5 g for men and < 6.5 g for women) [5]. Approximately 70% of dietary salt intake in Japan is attributable to common seasonings such as soy sauce and soybean paste [2]. Therefore, it is important to change not only individual dietary behaviors but also the food environment.

Excessive dietary salt intake increases blood pressure; thus, hypertension should be appropriately managed to prevent cardiovascular disease [6]. The prevalence of hypertension has decreased, but is still approximately 40–60% in Japan [7]. Sixteen million people will receive treatment for hypertension in 2023 [8], with 1.7 trillion yen spent on hypertension treatment, accounting for 3.6% of the total national medical expenditures of 46.7 trillion yen in 2022 [9]. However, the control rate of hypertension is low, at 20–30% in Japan compared with 50–60% in the United States [7]. Effective hypertension control should be enforced in combination with the prevention of hypertension, including salt reduction.

METHODS

Development of a national model

We constructed a system dynamics model for Japan using four sub-models: salt intake, population, hypertension, and treatment costs. We developed the salt intake sub-model for a fixed hypothetical population aged ≥ 20 years with a fixed number of foods. Sub-models of population, hypertension, and treatment costs were based on national statistics as reference data, and we calibrated the model parameters for each sub-model in a stepwise manner. We developed the model using Vensim Professional 10.2.0 (Ventana Systems Inc., Harvard, MA, USA). The unit of time was years, and we set the initial time, final time, and time step as 2012, 2040, and 0.0625 years, respectively.

Salt intake sub-model

Based on the fixed hypothetical population and the fixed number of foods, the salt intake sub-model comprised two stock-and-flow diagrams of co-flows [10]. On average, high- and low-salt foods were assumed to contain 14 and 6 g of salt, respectively. We chose these values to approximate the mean daily salt intake of 10.4 g ± 4.2 g (standard deviation) among people aged ≥ 20 years in the NHNS in 2012 [11]. We fixed the total number of foods at 1,000, and we assumed that 10% were initially low in salt in 2012. We calculated the daily salt content as a weighted mean of 14 g and 6 g based on the proportions of high-salt foods and low-salt foods, respectively. We set the rate of change of the flow from the stock of high-salt foods to that of low-salt foods at 0.04/year. We fixed the total population at 100,000, and determined the initial proportion with low salt intake via optimization. We also determined the change rate of flow from the stock of people with a high salt intake to the stock of those with a low salt intake by optimization. We calibrated these model parameters to the daily salt intake of participants aged ≥ 20 years in NHNS, annually from 2012 to 2023; surveys in 2020 and 2021 were canceled due to COVID-19 [11]. We calculated the daily salt intake as a weighted mean of 14 g and 6 g based on the proportions of people with high and low salt intake, respectively. We set daily salt intake by sex to differ consistently from that of both sexes combined, with gaps between the sexes combined and each sex in daily salt intake for participants aged ≥ 20 years in the NHNS in 2012 [11].

Population sub-model

The population sub-model comprises two stock-and-flow diagrams of the aging chains for men and women [10]. Each aging chain has four stocks in the 10-year age group from 40 to 79 years, with the respective population in 2012 as its initial value [12]. We set the transition rates for the flows between stocks to 0.1/year, corresponding to an inverse of 10 years. Individuals aged 39 years enter inflows into stocks aged 40–49 years by sex.

Hypertension sub-model

The hypertension sub-model comprises two aging chains of people with hypertension (PwH): men and women. The basic structure of the aging chain of this sub-model is the same as that of the population sub-model. For the initial values of each stock, we calculated the number of PwH by sex and age group by multiplying the respective population and proportions of hypertension (systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg) regardless of antihypertensive medication in 2012 using the NHNS data with permission from the Ministry of

Health, Labor and Welfare (MHLW). We calculated the inflow of individuals developing hypertension by sex and age group as the product of the proportion of individuals with high salt intake from the salt intake sub-model, the corresponding population size from the population sub-model, and the parameters. We calculated the outflows of deaths by sex and age group as 1.6 times the deaths from the respective stocks, based on findings from a nationally representative cohort of the Japanese population [13].

Treatment cost sub-model

The treatment cost sub-model comprised no stock-and-flow diagrams but was built on stocks for the numbers of PwH by sex and age group from the hypertension sub-model. We calculated treatment costs as the product of the number of PwH and the per-person outpatient treatment cost for hypertension. We estimated the outpatient treatment cost for hypertension per person by sex and age group by calibrating the annual outpatient medical expenditure for hypertension from 2012 to 2019 in the Medical Insurance Benefits Survey [14], using the weights described above.

Development of subnational models

We developed subnational models for the 47 prefectures separately using the same sub-models and parameters as the national model. The only exception was that we calibrated the model parameters for the outflows of deaths and migration in the population sub-model to population and death counts in each prefecture, by sex and age group, annually from 2012 to 2019 [10,11], using the weights described above.

In the salt intake sub-model, we applied a gap in daily salt intake for the participants aged ≥ 20 years of the NHNS in 2012 [11] between each prefecture and the whole country to the salt content (14 g and 6 g) of high- and low-salt foods to calculate prefecture-specific daily salt intake. In the hypertension sub-model, we used the ratio of the 2012 prefecture-level proportion of participants aged 40–79 years with hypertension to the national proportion, based on NHNS individual-level data with MHLW permission, to calculate prefecture-specific numbers of PwH.

We transferred relevant parameters of the prefectural models in Vensim Professional 10.2.0, which incorporated the national model, to each array using Stella Architect version 4.0 (ISEE Systems, inc., Lebanon, NH, USA), which incorporated the national model.

Scenarios

Using national and subnational models, we conducted simulations for the period 2012 to 2040 as the base run. In addition, we designed three hypothetical scenarios designed to simulate the effects of multiplying the change rates of food and people on daily salt intake, the number of PwH, and outpatient treatment costs for hypertension. We chose a multiplier of three to indicate extreme changes.

Scenario 1: the change rate of the foods multiplied by three

Scenario 2: the change rate of the people multiplied by three

Scenario 3: the change rates of both foods and people multiplied by three.

RESULTS

Simulated results of the national model as base run

In the salt intake sub-model, the initial proportion of people with low salt intake and the rate of change were determined by optimization to be 48.7% and 0.0786 per year, respectively. As a result of a decrease in the number of high-salt foods and people with high salt intake, the daily salt content of the foods would decrease from 13.2 g/day in 2012 to 9.9 g/day in 2040 (Figure 1), and daily salt intake would decrease from 10.1 g/day in 2012 to 8.7 g/day in 2040.

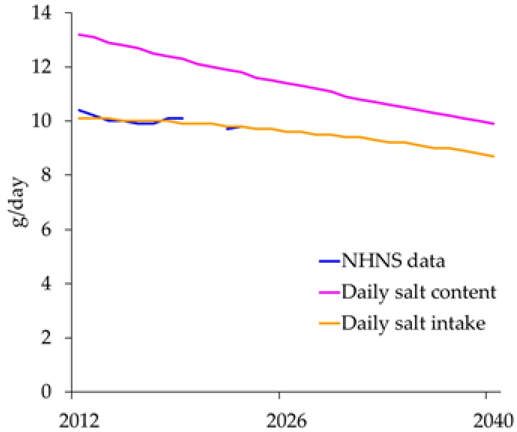

Figure 1. Daily salt intake in the NHNS (2012-2019, 2022, and 2023) and simulated changes in daily salt content and daily salt intake in the salt intake sub-model from 2012 to 2040 in the base run. NHNS, National Health and Nutrition Survey.

In the population sub-model, both men and women declined, and the decline was steeper for women. In the hypertension and treatment cost sub-models, both men and women declined, and the decline was steeper for men. In the hypertension and treatment cost sub-models, both men and women declined, and the decline was steeper for men. Simulated changes in PwH in men in their 40s and 50s showed a steeper decline from 2012 to 2040 than that in women.

Simulated results of the national model by scenario

In the salt intake sub-model, Scenario 1 had a larger impact on high-salt foods than Scenario 2. Scenario 2 had a greater impact on individuals with high salt intake and daily salt intake than Scenario 1, and Scenario 3 had the greatest impact on these variables.

In the hypertension and treatment cost sub-models, scenario 2 had a larger impact on PwH and treatment costs than scenario 1, whereas scenario 3 had the largest impact on these variables in both men and women. The differences relative to the base run were greater among women than among men, with respect to both PwH and treatment costs.

Simulated results of subnational models

The daily salt intake in 2012 ranged from 8.3 g/day in Okinawa to 11.7 g/day in Iwate, and these values decreased to 6.9 g/day and 10.3 g/day in the base run, respectively. A more than 10-fold difference was observed between Tottori and Tokyo in terms of population, PwH, and treatment costs.

The prefecture models were simulated for each scenario, yielding the corresponding results.

DISCUSSION

To our knowledge, this is the first study to use a national- and prefectural-level system dynamics model to assess the impact of reduced salt intake on medical expenditures for hypertension in Japan. Based on the national model, we developed prefectural models using each prefecture's population sub-model, and we simulated the numbers of PwH and outpatient treatment costs for hypertension for the base run and the three scenarios by prefecture. The methodology for developing subnational models based on the national model used in this study may be applied to other public health interventions for chronic diseases.

Because the Japanese population shares a common food environment, with 70% of its dietary salt from seasonings [2], we calculated the daily salt intake for a fixed population of 100,000 people, and applied the proportion to national and prefectural populations. In 2012, we arbitrarily classified only 10% of 1,000 foods as low-salt. This means that the weighted mean of 90% of the foods weighing 14 g (high-salt foods) and 10% of the foods weighing 6 g (low-salt foods) was 13.2 g in 2012. The discrepancy in the daily salt intake of 10.4 g in 2012 [11] could be explained by the abundant availability of seasonings in supermarkets, convenience stores, and restaurants. As shown in the simulated changes in daily salt intake using reference data from the NHNS (Figure 1), the daily salt content closely matched the reference data, with an MAPE of 1.0%. In addition, the daily salt content of the foods decreased by 25% from 13.2 g/day in 2012 to 9.9 g/day in 2040, whereas the daily salt intake decreased by 14% from 10.1 g/day in 2012 to 8.7 g/day in 2040. Thus, the findings indicate that the daily salt content should be lowered more intensively than the daily salt intake.

This study has several limitations. First, hypertension is a risk factor for chronic diseases, such as cardiovascular and chronic kidney diseases [6], and the treatment of these diseases greatly contributes to medical expenditure in Japan; this study exclusively focused on hypertension. A comprehensive model of public health interventions for chronic diseases, such as PRISM in the United States [15,16], should be developed by expanding the current model. Second, although we incorporated deaths due to hypertension into the hypertension sub-model, we did not feedback changes in deaths according to scenarios into the population sub-model. As mortality (per 100,000) from hypertensive diseases (9.8) only accounted for 0.7% of all-cause mortality (1334.5) in 2024, the effects of this omission seem minor in the current model. This issue should be resolved when we expand the current model to include cardiovascular and chronic kidney diseases.

In conclusion, the national and prefectural system dynamics models indicate that reducing salt intake could reduce PwH and treatment costs by 2040. These simulation models could help national and local government policymakers promote salt reduction to reduce medical expenditures in Japan.

REFERENCES

1. Saito A, Imai S, Htun NC, Okada E, Yoshita K, Yoshiike N, et al. The trends in total energy, macronutrients and sodium intake among Japanese: Findings from the 1995-2016 National Health and Nutrition Survey. Br. J. Nutr. 2018, 120, 424-434.

2. Matsumoto M, Tajima R, Fujiwara A, Yuan X, Okada E, Takimoto H. Trends in dietary salt sources in Japanese adults: data from the 2007-2019 National Health and Nutrition Survey. Br. J. Nutr. 2023, 129, 690-703.

3. The National Health and Nutrition Survey. Tokyo; 2025. https://www.mhlw.go.jp/content/001435384.pdf.

4. World Health Organization (WHO). Guideline: Sodium Intake for Adults and Children. 2012. https://www.who.int/publications/i/item/9789241504836.

5. Ministry of Health, Labour and Welfare. Dietary reference intakes for Japanese, 2025. https://www.mhlw.go.jp/content/10904750/001316585.pdf.

6. Ohya Y, Sakima A, Arima H, Fukami A, Furuhashi M, Ishida M, et al. Key highlights of the Japanese Society of Hypertension Guidelines for the management of elevated blood pressure and hypertension 2025 (JSH2025). Hypertens. Res. 2025, 48, 2500-2511.

7. Hisamatsu T, Miura K. Epidemiology and control of hypertension in Japan: a comparison with Western countries. J. Hum. Hypertens. 2024, 38, 469-476.

8. Ministry of Health, Labour and Welfare. Summary Report of Patient Survey 2023. 2024. https://www.mhlw.go.jp/english/database/db-hss/sps_2023.html.

9. Ministry of Health, Labour and Welfare. Overviwew of National Medical Care Expenditure 2022. 2024. https://www.mhlw.go.jp/toukei/saikin/hw/k-iryohi/22/index.html.

10. Sterman JD. Business dynamics: systems thinking and modeling for a complex world. Irwin McGraw Hill; 2000.

11. Ministry of Health Labour and Welfare. National Health and Nutrition Survey. https://www.mhlw.go.jp/bunya/kenkou/kenkou_eiyou_chousa.html.

12. Statistics Bureau of Japan, Ministry of Internal Affairs and Communications. Population Estimates. https://www.stat.go.jp/english/data/jinsui/index.html.

13. Ueshima H, Iimura O, Iida M, Okayama A, Sawai K, Minowa M. Impact of elevated blood pressure on mortality from all causes, cardiovascular diseases, heart disease and stroke among Japanese: 14 year follow-up of randomly selected population from Japanese - Nippon data 80. J. Hum. Hypertens. 2003, 17, 851-857.

14. Ministry of Health Labour and Welfare. Medical Insurance Benefits Survey. https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/iryouhoken/database/zenpan/iryoukyufu.html.

15. Homer J, Milstein B, Wile K, Pratibhu P, Farris R, Orenstein D. Modeling the local dynamics of cardiovascular health: Risk factors, context, and capacity. Prev. Chronic Dis. 2008, 5, A63.

16. Hirsch G, Homer J, Trogdon J, Wile K, Orenstein D. Using simulation to compare 4 categories of intervention for reducing cardiovascular disease risks. Am. J. Public Health. 2014, 104, 1187-1195.