The Modeling Impact of Different Food Policy Scenarios on Incidence and Mortality from type 2 Diabetes in Azar Cohort Population

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Abstract

Background: Given the impact of high intake sugar sweetened beverages on type2 diabetes, intervention to reduce their consumption can be a top priority for any health system. Thus, the purpose of the present study is to simulate the impact of policy options related to reduce consumption of sugar-sweetened beverages on the prevalence and mortality of type 2 diabetes in Iranian men and women.

Methods: A Markov micro-simulation (MM) model was used to predict the effect of several policy options on the incidence and death from type 2 diabetes in Azar Cohort Databases. Population age-and sex-specific prevalence and incidence rate of diagnosed diabetes were derived from the national health data. The PRIME model was used for coding the input parameters of simulation using R and Python software.

Results: The prevalence and mortality rate of type 2 diabetes under the scenario of reduced consumption of sugar sweetened beverages indicated that the highest and lowest prevalence and mortality rates of type 2 diabetes for men and women were related to no policy condition and replacing sugar-sweetened beverages with healthy drinks such as water, respectively. Also, the maximum number of death postponed/prevented from type 2 diabetes was related to replacing sugar-sweetened beverages with water and levying 10% tax on sugar sweetened beverages, respectively.

Conclusion: Regarding the effect of simulating different policy options on reducing the consumption of sugar sweetened beverages, the most effective policy options were replacing sugar-sweetened beverages with water.

Key Messages

Implications for policy makers:

- Based on the results of this study, the most effective policy options on reducing the consumption of sugar sweetened beverages, incidence, and mortality from type 2 diabetes were replacing sugar-sweetened beverages with water.
- the less effective policy options on reducing the consumption of sugar sweetened beverages ,incidence, and mortality from type 2 diabetes were excising 10% tax on sugar sweetened beverages.
- The Integrating reformulation and 10% tax on sugar sweetened beverages were more effective than excising 10% tax on sugar sweetened beverages or reformulating sugar sweetened beverages policy options in preventing incidence and mortality from type 2 diabetes.

Implications for the public:

Non-communicable Diseases (NCDs) are one of the main global public health problems, particularly in developing countries. Unhealthy diet such as consumption of sugar sweetened beverages is one of the modifiable risk factor in incidence and mortality from type 2 diabetes. In the present study, we aimed to simulate the effects of best policy options for reducing consumption of sugar sweetened beverages. We found that replacing sugar-sweetened beverages with water and integrating reformulation and 10% tax on sugar sweetened beverages were the best policy scenario on reducing the consumption of sugar sweetened beverages, incidence, and mortality from type 2 diabetes in Azar cohort population.

Introduction

Non-communicable diseases are a threat to achieving the Millennium Development Goals of the United Nations and the Sustainable Development Goals after 2015. The rapid increase in non-communicable diseases, especially through the increase in household expenditure on health care, is expected to prevent the success of the poverty reduction plan in low-income countries.

Diabetes mellitus (DM) is a high prevalent leading cause of mortality in the Middle East and North Africa (MENA) region. It is estimated that about 35 million people are living with diabetes in this region. Iran is amongst the countries with the highest prevalence of DM in the region with 8.9% in the adult population[(2)].

Unhealthy diet (containing high carbohydrate, fat, red meat and low fiber), tobacco, alcohol and physical inactivity are the major risk factors in developing the majority of NCDs[(3)].

These diets and wrong habits are associated with an increased consumption of sugar-sweetened beverages (SSBs) containing excess amounts of sugar and calorie, which may lead to type 2 diabetes because of its effect on weight gain, as well as its glycemic effects—inducing rapid spikes in glucose and insulin, causing insulin resistance[4, 5].

Worldwide, several upstream and downstream interventions such as improving consumer information, taxation, and reformulation of SSB etc. have been proposed to reduce SSB consumption and prevent diet-related NCDs[6]. However, the effect of these policy options on the incidence and mortality of type 2 diabetes are broad and potentially confusing. With rising healthcare costs related to the care of type 2 diabetes and several policy implementation and limited resources in this area in Iran, it is necessary to determine and compare the impact of several policy options to reduce SSB consumption for lowering the incidence of type 2 diabetes and its resulting mortality in Iran.

Regarding food and nutrition policies, due to the lack of sufficient perspective on the impact of various policies and reducing the nutritional risk factors of non-communicable disease, the existing data using statistics and simulation can inform the effects and success rates of different policies in the population. Computer simulation is a powerful tool to inform policymakers about the consequences, strengths, and weaknesses of different policy options before implementation. Nowadays, these methods are used in different countries of the world as one of the most basic methods of macro-decision-making and policy-making [7–9].

To the best of our knowledge, there is no simulation study which compared the effects of several nutrition policies to reduce SSB consumption for decreasing type 2 diabetes. Accordingly, this study aimed to simulate the impact of several nutrition policy options for reducing SSB consumption to the incidence and death of type 2 diabetes.

Materials And Methods

1-The Model overview and structure

This study used the Preventable Risk Integrated Model (PRIME) to simulate effects of different scenarios on age-specific and sex-specific mortalities from type 2 diabetes in Iran. The PRIME model is a scenario-based model that links 12 behavioral risk factors such as diet, physical inactivity, alcohol consumption and tobacco consumption with NCD mortality[10]. This model have 24 health outcomes including cardiovascular diseases, cancers, kidney disease, liver disease, chronic obstructive pulmonary disease, as well as type 2 diabetes. This framework is parameterized using the best available evidence from meta-analyses of epidemiological studies: prospective cohort studies for links dietary risk factor with NCD mortality[11, 12].

PRIME requires data on prevalence of modifiable risk factors, mortality rates, and population estimates by 5-year age groups and sex, for both baseline and counterfactual scenarios. For this study, PRIME was used to estimate the number and death rate of type2 diabetes that would be delayed or averted in the studied population. The baseline scenario (no policy option) used the current levels of modifiable risk factors in those living in areas, where the counterfactual scenario involved applying the level of risk factors.

2-The model inputs

2-1-Population data

This study used the data from the Prospective Epidemiological Research Studies in Iran (Persian cohort) study results of Azar Cohort (azarcohort.tbzmed.ac.ir) in Shabestar, East Azerbaijan province (North West of Iran) in Iran[13]. The AZAR Cohort Study is a prospective study assessing the risk factors related to the most prevalent NCDs in East Azerbaijan province. The more details about the Azar cohort study has been explained in other published article .[14] The inclusion criteria were: (i) permanent residence in Shabestar district (minimum of 9 months); (ii) written informed consent; (iii) at least one Azeri parent; and (iv) age between 35 and 70 years at the time of enrolling in the study. Exclusion criteria were: (i) having a diagnosis of a disabling psychiatric disorder; and (ii) having a diagnosis of a disabling physical illness.

2-2-Dietary intake assessment

Nutritional status was assessed using Food Frequency Questionnaire (FFQ). The FFQ assessment asks about consumption of food and drink during the past year. The questionnaire includes 125 food items appropriate for the Iranian population, including bread, cereal, grains, meat and meat products, milk and dairy products, vegetables, fruits, types of oil and oilseeds, sugar, miscellaneous food products, spices and food supplements. Also some local foods were added into the questionnaire. The nutrition questionnaire also asks about cooking methods, food preservation, food storage, cooking styles and use of herbal medicines and drinks.

To help the respondent's memory and increasing accuracy and precision of participants responds, household scales, including glasses, teaspoons, tablespoons, and colored photographs of portion size were used during the interview. All participants provided an answer to their frequencies of food intake (daily, weekly, monthly and annually) according to standard portion size for each food item, then each participant's reported intake was transformed to weight using standard Iranian household measures. Dietary information was converted to energy and nutrients using revised Nutritionist IV software [Nutritional Database Manager 4.0.1, Nutritionist IV, version 3.5.2][15]. The data of 12126 participants from Azar cohort study were used for 2015 years. The general characteristics of population including age, sex, marital status, education, and SSB consumption are reported in Table 1. SSBs were defined as any sugar sweetened sodas, fruit drinks, sports/energy drinks, sweetened iced tea, or homemade SSBs, which contained at least 50 kcal per 8-oz serving, with 100% fruit juice being excluded.

2-3-Diabetes definition

The prevalence of type 2 diabetes were determined according to self-reporting of participants.

2-4-Effects of SSB Intake on Diabetes Mellitus

Effects of SSB consumption on diabetes mellitus were based on a meta-analysis of 8 prospective cohorts with a total of 310819 participants and 15043 cases of type 2 diabetes mellitus. In this meta-analysis, individuals in the highest category of SSB intake (1–2 servings/d) had a 26% greater risk of developing type 2 diabetes mellitus in comparison with those in the lowest category of SSB intake (none or <1 serving per month; risk ratio, 1.26; 95% CI,1.12–1.41). The association between SSB intake and risk of type 2diabetes mellitus in this meta-analysis was consistent across sex and ethnic groups, which included blacks, whites, and Asians. Although there was heterogeneity across the studies (I2=66%), all but one showed positive associations between SSB intake and risk of type 2 diabetes mellitus, with the strength of the association increasing with the study size and duration[4].

2-5-Cause-Specific Mortality by Age and Sex

According to the Derakhshan et al.'s study, the incidence rate of type 2 diabetes in Iranian men and women was 9.36 and 10.1 per 1,000 persons annually respectively. Note that these rate were calculated separately for different individuals according to age and sex[16].

The mortality rate of type 2 diabetes in the study population in 2015 was based on the data from the National and Subnational Burden of Diseases, Injuries, and Risk Factors in Iran (NASBOD)[1].

2-6-Selected Policy Scenario

According to our earlier report about priotrizing policy options related to reducing the burden of non-communicable diseases in Iran[17], we selected several policy scenarios for the simulation:

1- No policy scenario: assuming the current situation is maintained and no special policy is implemented, the rate of change in the SSB consumption and disease burden during the 20 years was simulated.

2- Applying 10% tax on SSB:According to Afshin et al.'s meta-analysis, a 10% increase in the price of SSB would reduce the consumption by 7%. Thus, the amount of sugar sweetened beverages consumed in a given year (for example, 2016) for each age and sex was estimated[18]. Also, given the differences in consumption levels in response to tax across different socio-economic situations, individuals were divided into five groups based on different socio-economic where the changes in the SSB consumption following excising 10% tax were considered within 4-10%[19].

3- Replacing SSB with water:In this scenario, the SSB has been replaced with water, where zero consumption of these drinks has been considered[20, 21].

4- Changing the reformulation of SSB through reducing the sugar content of SSB by 30%[22].

5- Applying 10% tax on SSB along with changing the formulation of SSB via reducing the sugar content of sugary drinks by 30%.

3-Model output

3-1-Estimation of Deaths Prevented or Postponed (DPP)

This model has been used to estimate the number of deaths prevented or delayed because of type 2 diabetes after implementing a specific policy. According to the methodology of a similar study to obtain preventable or delayed death in the case of implementing a policy option in an age and sex group, the desired command code was written based on the following mathematical calculation and implemented in the software. As each policy option increases or decreases the amount of nutrients consumed, the effect of changes in the consumption on reducing or increasing the risk is calculated using the following formula:

$$1 - exp\left(log(RR) \times \left(\frac{B}{A}\right)\right)$$

Where, RR= Relative risk between SSB consumption level in baseline and type 2 diabetes extracted from meta-analyses; A=current amount of SSB consumed in the target state in terms of serving per day in the age and sex group; B= The amount of SSB consumption after implementing the desired policy option in terms of serving per day. The number obtained from the above formula is multiplied by the number of deaths due to type 2 diabetes while no policies are implemented. Also, the number death postpone or prevented under specific scenario were calculated by subtracting the total number of deaths due to the type 2 diabetes under specific scenario from the number deaths due to the type 2 diabetes under no policy scenario[19]. This study was approved by Ethics Committee in Shahid Beheshti University of Medical Sciences (Ethics No. IR.SBMU. NNFTRI.1397.056).

4-Analyses

We used Monte Carlo simulation to quantify the uncertainty in the attributable deaths from SSB intake data (which includes both measurement and sampling error as well as modeling uncertainty), and uncertainty from the relative risks in our final estimates. Each policy scenario simulated 1000 times and mean and standard error of iteration were reported. For each mean exposure, population-representative standard deviations were predicted using coefficients from regressions performed on all available dietary survey data in our collection, where the standard deviation was the dependent variable while the mean was the independent variable[23, 24]. All analyses were performed using R and Python software, version 2.15.0.

Results

The impact of policy options on reducing the consumption of SSB has been simulated in the Azar cohort population. Specifically, 57.1% of the studied population were women and 92.40% were married. Also, 18.78% of the study population were illiterate, 50.15% had primary literacy, 12.94% was mid school graduated, 10. 40% had a diploma degree, and only 7.73% had a bachelor's degree or higher. In 2015, about 11.65% of people had type 2 diabetes, with the prevalence of diabetes being 12.51% in women and 10.50% in men (Table 1).

Table 1
Baseline demographic characteristics of study population

Total (n=12126)	Female (n=6921)	Male (n=5205)	Variable
49.53±9.28	48.92±9.26	50.25±9.25	Age(year)*
			Education level (frequency)
2277 (18.78%)	1762 (25.46%)	515 (9.89%)	Illiterate
6082 (50.15%)	3435 (49.63%)	2647 (50.86%)	Elementary
1569 (12.94%)	739 (10.68%)	830 (15.95%)	Mid school
1261 (10.40%)	655 (9.46%)	606 (11.64%)	High school graduated
937 (7.73%)	330 (4.77%)	607 (11.66%)	University education
			Marital Status
921 (7.60%)	862(12.46%)	59(1.13%)	Not married
11205 (92.40%)	6059(87.54%)	5146(98.87%)	Married
1413 (11.65%)	866 (12.51%)	547 (10.51%)	Type 2 diabetic patients (frequency)
49.00±8.1	38.57±7.35	62.88±8.29	Sugar sweetened beverages daily consumption* (ml/day)

* The results were expressed as mean± Standard Deviation

The effects of simulating different policy options on the prevalence of type 2 diabetes are presented in Table 2. Comparing the different simulated policy options, the no policy scenario was associated with the highest prevalence of diabetes in men and women, while replacing SSBs with water and levying 10% tax on these drinks, along with reformulation of SSBs, had the greatest effect on reducing the prevalence of type 2 diabetes in men and women, respectively. Applying 10% tax had the minimum effect on reducing the prevalence of type 2 diabetes.

Table 2
Estimated number and prevalence of type 2 diabetes during 20 years under different policy scenarios, by gender

Variables	2025				2035			
	female		male		female		male	
Policy scenario	n (95% CI)	Prevalence (%)	n (95% CI)	Prevalence (%)	n (95% CI)	Prevalence (%)	n (95% CI)	Prevalence (%)
No policy	1538 (1524,1547)	21.98	997 (986,1002)	18.16	1783 (1769,1791)	26.12	1334 (1326,1347)	24.51
10% tax of SSB	1431 (1426,1448)	20.43	931 (925,939)	17.30	1659 (1647,1666)	24.30	1243 (1231,1250)	23
reformulation	1111 (1007–1128)	15.86	712 (707–719)	13.23	1428 (1419,1435)	20.91	1003 (995,1014)	18.56
Water substitution	857 (785,890)	12.24	548 (540,553)	10.18	953 (881,983)	13.95	626 (635,621)	12.58
Integrated reformulation and tax	1001 (992,1108)	14.29	651 (642,667)	12.09	1163 (1155,1176)	17.03	868 (860,875)	16.06

The simulation of different policy options for reducing the consumption of SSB on the mortality associated with type 2 diabetes over 20 years indicated that no policy option resulted in 7 and 11 deaths related to type 2 diabetes for women and 7 and 8 for men, respectively. The lowest mortality rate from type 2 diabetes was related to implementing the "replacing SSB with water" policy option. In general, the implementation and non-implementation of policy options more affected women's mortality rate from type 2 diabetes as compared to men's (Table 3).

Table 3
Estimated number of deaths prevented under different policy scenarios, by gender during 20 years

Variables	2015 until 2025				2026 until 2035				Total	
	female		male		female		male			
Policy scenario	n (95% CI)	Death rate per1000	n (95% CI)	Death rate per1000	n (95% CI)	Death rate per1000	n (95% CI)	Death rate per1000	DPP	DPP/10^5
No policy	314 (282,391)	8	305 (252,376)	7	953 (881,983)	11	858 (785,890)	9	-	-
10% tax of SSB	189 (176,201)	5	172 (163,180)	6	111 (100,132)	8	128 (98,145)	7	1599	435
reformulation	170 (158,182)	4	166 (155,179)	5	97 (79,107)	6	107 (87,125)	6	1789	487
Water substitution	143 (128,151)	3	134 (119, 142)	2	76 (59,86)	4	62 (49,75)	3	2015	548
Integrated reformulation and tax	158 (134,170)	4	141 (125, 159)	3	102 (83,124)	5	87 (93,69)	4	1872	510

The results of simulating policy options on DPP from type 2 diabetes showed that the lowest (1599) and highest (2015) DPP levels were related to levying 10% tax on SSB and replacing SSB by water respectively (Table 3).

Discussion

The results of different policy options simulations on the prevalence and mortality from type 2 diabetes showed that comparing the policy options, replacement of SSB with water over 20 years would lead to the greatest reduction in the prevalence and mortality of type 2 diabetes while no policy condition would lead to an increase in them across the studied population. The lowest and highest number of deaths prevented or postponed were related to 10% tax (1599 death cases) and SSB replacement with water (2015 death cases), respectively. Also, reformulating SSB over 20 years can prevent 1789 deaths caused by type 2 diabetes. (Table 3).

Previous studies have shown that consuming SSB increases the risk of non-communicable diseases such as type 2 diabetes. Thus, reducing the consumption of these drinks is one of the policy priorities for preventing non-communicable diseases. One of the proposed strategies in this regard is to replace sugary drinks with water. In this regard, the findings of interventions based on reducing the consumption of SSB through replacement with water indicated the effectiveness of this strategy in preventing obesity and type 2 diabetes[20].

Evidence suggests that replacing SSB with water or low-calorie drinks and milk has a positive effect on reducing their consumption[25]. Replacing SSB with milk instead of non-calorie drinks such as water can help provide minerals and vitamins to poor and unhealthy diets. The potential effects of milk on bone health are also obvious, and daily consumption is associated with a reduction in the body fat or body mass index. Further, the milk protein may help increase lean body mass[6, 26]. Findings from the study by Stookey et al. (2007) also found that substituting calories in SSB with water could help people lose weight, thus reducing their risk of developing chronic diseases such as diabetes, which was consistent with the findings of the present study[21].

Note that the findings of the effect of replacing water on weight loss and thus preventing diabetes are contradictory. For example Tate et al reported that the Replacement of caloric beverages with non-caloric beverages as a weight-loss strategy resulted in average weight losses of 2% to 2.5[27]. in the studies conducted by Pan et al and Piernas et al, replacing SSB with water led to a significant increase in fruit and vegetable consumption, as well as improved biomarkers associated with type 2 diabetes such as fasting blood glucose and improved hydration[28, 29]. But, in contrary, Ebbeling et al indicated Home delivery of low calorie beverages (e.g., bottled water and “diet” beverages) during 25 weeks resulted in insignificant net difference in body mass index between intervention and control group[30]

In another report, this strategy resulted in a 12% reduction in SSB consumption and 4% increase in the consumption of other beverages such as water by the end of 2014, which was in accordance with our results[31].

Replacing SSB with water seems to be an optimistic scenario and it seems relatively impossible to completely replace water in the real world. Meanwhile, the findings of several studies have shown that by providing education on nutrition and counselling, and especially improving access to water through family-based interventions for example by sending free water to homes, success can be achieved in this regard. Also, a review study has concluded that educational interventions and providing water to increase water consumption by reducing its prices or multiple community-based interventions in this field have been more successful in reducing SSB consumption[32]. In a British study, it was estimated that replacing SSB partly with water or tea or coffee could reduce the incidence of type 2 diabetes by 14 to 25%[33].

The reformulation of SSB by reducing the energy density per serving of the beverage is one of the proposed policies of different countries to reduce the SSB consumption. The mandatory reformulation of SSB to reduce sugar and energy density of SSB as part of the UK's public health contract is the most obvious example of this scenario. This program was launched in 2012 by the UK Department of Health to help the food and beverage industry contribute to helping people reduce their calorie intake. Meanwhile, in a modeling study in Australia, it was reported that reformulation of SSB was one of the most cost-effective policies in the prevention of non-communicable diseases[34]. According to the literature review, our study is the first to compare the effectiveness of this policy option with other options to reduce the prevalence and death related to type 2 diabetes. The results indicated that compared with no policy and taxation scenarios, the reformulation has a greater impact on reducing the prevalence and mortality of type 2 diabetes.

In the present study, in comparison with other policy scenarios (except for no policy implementation scenario), applying a 10% tax on SSB had minimum effect on reducing the incidence and mortality of type 2 diabetes.

Fiscal tools such as taxation are other common policies to control unhealthy food consumption. Mexico and New Zealand are leading countries in levying tax on SSBs, which have been relatively successful[35]. A modeling study estimated that a 10% elevation in the SSB prices in the Mexican adults from 2013 to 2022 would reduce 189300 cases of type 2 diabetes and save $ 983 million in Mexico[36]. In

Australia, the tax could save 112,000 years of healthy living for men and 56,000 years for women, and could also lower the total cost of health care by 609 million dollar. Indeed, this policy would reduce the number of new cases of type 2 diabetes by about 800 people per year. Twenty-five years after the introduction of the tax, there would be 4,400 fewer cases of heart disease and 1,100 fewer people with stroke. The tax could generate about $ 400 million in revenue each year[37]. The results of a meta-analysis study showed that applying a 10% tax on unhealthy foods can reduce the consumption of these foods by an average of 7%[18].

According to previous studies, the tax on SSB in people with low socioeconomic status leads to a further reduction in the purchase or consumption of SSBs. Backholer et al. (2017) reported that applying 10% tax on SSB can lead to a 3–10% reduction in SSB consumption which varied across different social and economic classes of people consuming these beverages[38]. The strength of our study was to consider this division in individuals based on contextual indicators such as education level, income, employment in different social and economic groups, which ultimately predicted that 10% tax on SSB would prevent 1599 deaths from type 2 diabetes in 20 years.

On the other hand, in some studies, experts have suggested that the tax on SSB should be 20% or larger to have a significant effect[39, 40]. Alternatively, it should be combined with other policy interventions. In our study, the combination of taxation with reformulation of SSB reduced the 1872 deaths from type 2 diabetes.

In several studies, the mechanism of the effect of tax on SSB on reducing the prevalence and mortality of diabetes has been discussed. The most important mechanism is reducing calorie intake and thus encouraging weight loss, thereby preventing type 2 diabetes and consequently increasing life expectancy[18].

In parallel with our results, previous studies indicated that fiscal policy alone was not effective in reducing SSB consumption[41, 42].

As noted, the mortality rate of type 2 diabetes in the implementation and non-implementation of policy options over a 20-year period was generally higher for women than for men. Findings by Papier et al. (2017) showed a significant correlation between the rate of type 2 diabetes in women and SSBs, while in men, there was no significant correlation between SSBs and type 2 diabetes [24]which was consistent with the findings of the present study. Other studies in African, Caucasian, and Asian populations have also shown a significant correlation between SSB and an increased risk of type 2 diabetes in women compared to men [23, 43, 44].

To the best of our knowledge, the present study is the first to simulate the impact of nutritional policy options on incidence and mortality from type 2 diabetes in Iran, could anticipate the effectiveness of the policy before implementing policies. Our study also used the death postponed or prevented variable, which is more practical and understandable than other cost-effectiveness indicators for health policy makers[45].

Declarations

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Ethical issues

This study was approved by Ethics Committee in Shahid Beheshti University of Medical Sciences (Ethics No. IR.SBMU. NNFTRI.1397.056).

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

HEZ, SP, and NK conceived the idea, designed the data analysis and simulation model, and drafted and edited the manuscript. AO, JST, and EF also contributed to the design of the data analysis and reviewed and edited the article. SP conducted the data analysis and

constructed the simulation model. HEZ, NK, JST, and AO reviewed results from the data analysis and simulation model.

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