Preventive Medicine Reports 19 (2020) 101150

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

# Simulations of future cardiometabolic disease and life expectancy under counterfactual obesity reduction scenarios

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ARTICLE INFO

*Keywords:*
Forecasting
Simulation
Obesity
Life expectancy
CVD
Health impact assessment

ABSTRACT

The aim of this study was to provide decision makers with an assessment of potential future health effects of interventions against overweight and obesity (OWOB). By means of the DYNAMO-HIA tool we conducted a health impact assessment simulating future prevented disease (ischemic heart disease (IHD), diabetes, stroke, and multi morbidity) incidence, prevalence and life expectancy (LE) related to a scenario where OWOB is reduced by 25% and a scenario where obesity is eliminated. The study covered projected number of persons living in Copenhagen, Denmark during year 2014–2040 (n 2040 = 742,129). Reducing the proportion of men/women with OWOB with 25% will increase population LE by 2.4/1.2 months and at the same time decrease LE with diabetes by 3.1/2.2 months. As a result of eliminating obesity, total LE will increase by 6.0/3.6 months and LE with diabetes will decrease with 9.8/10.3 months for men/women. We found no important effects on LE with IHD and stroke. This illustrates that the positive effects of lowering OWOB levels on IHD and stroke incidence is offset due to increasing total LE. Although the population of Copenhagen is relatively lean, reducing obesity levels will result in significant benefits for population cardiometabolic health status and LE. Future public health prevention programs may use the results as reference data for potential impact of reductions in OWOB.

## 1. Introduction

Obesity defined by a body-mass-index (BMI) above 30 is associated with reduced quality of life, adverse health outcomes and lower life expectancy (Ogden et al., 2007). As a result of improvements in medical and clinical treatment, death ascribed to and obesity-related diseases covering amongst others diabetes and ischemic heart disease (IHD) have decreased. Thus, these diseases often become chronic and lifelong. Obesity is now the fourth leading cause of loss in Disability-Adjusted Life Years (DALYs) worldwide, and in Denmark accounting for 6.6% of DALYS after smoking, high systolic blood pressure and alcohol misuse (GBD Compare, n.d.). The World Health Organization has stated in the European Food and Nutrition Action Plan for 2015–2020 to halt the increase in obesity (WHO regional office for Europe, 2014). In Copenhagen Municipality, Denmark, obesity increased over a period of 17 years (1987–2004) by 4.3% annually (Juel and Ekholm, 2015) and has in recent years reached a plateau (Stockmarr et al., 2016). Today, the proportion of persons with obesity in Copenhagen is 11% among men and women (Lau et al., 2015). Although the health benefits of weight reductions at the individual level is well-established (Ogden et al., 2007), less is known about the effects of reducing population obesity prevalence on future development of diseases and the consequences for future provision of healthcare (Levy et al., 2011).

In the planning phase of population prevention programs estimated health gains typically involve analyses that require a wide range of data including information on demography, lifestyle, disease, mortality, and epidemiological evidence. Health impact assessment (HIA) tools have been developed to support researchers and public health authorities (Kemm, 2008). Such tools model the dynamic relations between the distribution of risk-factor exposures in the population, and disease and mortality outcomes. HIAs are attracting more attention within public health planning and policy and have been used in single cases for

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https://doi.org/10.1016/j.pmedr.2020.101150
Received 12 September 2019; Received in revised form 7 March 2020; Accepted 14 June 2020
Available online 18 June 2020

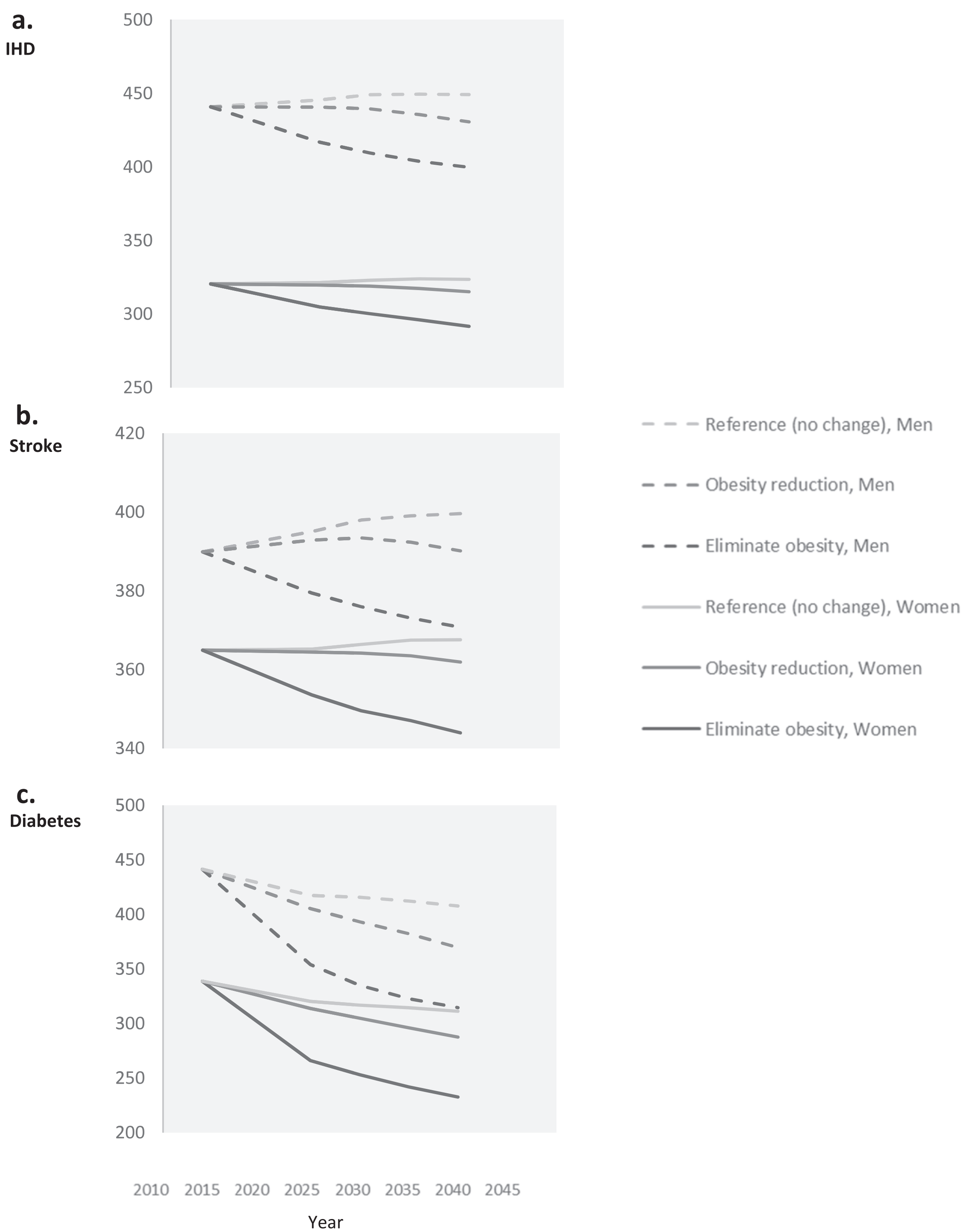


**Fig. 1.** a–c. Projected disease incidence rates (cases pr. 100.000 persons) development year 2014–2040, adjusted to year 2040 age distribution.

several decades in for instance members of the Healthy Cities Network (Kemm, 2013), and are in addition being rolled out as stand-alone activity in several countries (e.g. England) (WHO, 2013). Relatively few studies have simulated long-term health effects of changes in health behavior by means of dynamic quantitative HIAs, among these three studies simulating the consequences of obesity on population disease and mortality (Boshuizen et al., 2012; Lhachimi et al., 2013, 2016). Thus, simulation models of future prevalence of disease remain underutilized in chronic disease prevention research (Smith et al., 2014).

The aim of this study is to make projections of changes in incidence and prevalence of diabetes, IHD, stroke and multi-morbidity (combinations of the three diseases) according to the three overweight and obesity (OWOB) scenarios; a. no change in BMI (reference); b. OWOB reduction and c. eliminating obesity. Additionally, the aim was to to quantify potential gains in life expectancy by year 2040.

Scenario b., in which a 25% reduction in population OWOB prevalence is modelled, approximately corresponds to an annual decrease of 1%. We consider this to be an ambitious but realistic development if preventive actions are being implemented. To illustrate the full potential health gains, scenario c. estimates effects of eliminating obesity while keeping prevalence of overweight constant. To quantify expected effects of scenario b. and c. results are compared with scenario a. (reference) in which OWOB levels stay constant over time.

**Table 1**
Projected incident disease (cases pr. 100,000 persons) in year 2040.

| | Cases, n | | | Difference from reference scenario, n (%) | | |
|---|---|---|---|---|---|---|
| | IHD | Diabetes | Stroke | IHD | Diabetes | Stroke |
| Men | | | | | | |
| *Reference* | *449* | *408* | *400* | – | – | – |
| Obesity reduction | 431 | 370 | 390 | −19 (−4) | −38 (−9) | −10 (−2) |
| Eliminate obesity | 400 | 314 | 371 | −50 (−11) | −93 (–23) | −29 (−7) |
| **Women** | | | | | | |
| *Reference* | *321* | *311* | *364* | – | – | – |
| Obesity reduction | 313 | 288 | 358 | −8 (−3) | −24 (−8) | −6 (−2) |
| Eliminate obesity | 289 | 232 | 341 | –32 (−10) | −79 (−25) | −24 (−6) |

IHD, Ischaemic Heart Disease.

## 2. Methods

### 2.1. The DYNAMO-HIA model

DYNAMO-HIA is a Markov-type model; a dynamic simulation model that projects development in morbidity and mortality. It uses micro-simulation for risk-factor modelling which is combined with macro-simulation for calculating disease prevalence (Boshuizen et al., 2012). Conceptually, DYNAMO-HIA links risk-factor states to transition probabilities, which define the likelihood that an individual in a specific risk-factor state will shift to another risk-factor state over time (e.g. the probability an overweight person attaining normal body weight) (Lhachimi et al., 2012). Simulations follow the assumed causal pathway, in which population risk-factor exposure is linked to incidence of one or more diseases and mortality by use -of relative risks. For example, in the case of two diseases, there are four health states: the probability of having neither disease, only one of the diseases, or both diseases (Boshuizen et al., 2012). One or more counterfactual scenarios are used as benchmarks, in which the population-risk-factor-prevalence is set to a new level (e.g. goals set by politicians or analysts). These benchmark scenarios are compared to a reference scenario, typically with future risk-factor prevalence at a level reflecting current risk-factor development. The reference and counterfactual scenario(s) are modelled independently from another, and can be defined such that the new risk-factor levels are reached gradually over the simulation period, and health effects of the risk-factor exposure levels alike are developing over time (Lhachimi et al., 2012).

### 2.2. Data

Input data cover projections of population distribution from Statistics Denmark, data on morbidity based on hospital contacts (Schmidt et al., 2015) and mortality from Danish administrative registers (Pedersen, 2011), data on BMI class distribution from the 2013 Copenhagen Country Health Profile (Robinson et al., 2014), and relative risks from the literature linking OWOB to disease, and disease to other diseases and mortality. Following, these input data are described in detail.

Data on disease and mortality was linked by means of unique person identifiers given at birth or immigration. In Denmark researchers are entitled to use registers for research purposes without persons' informed consent as long as the researchers comply with predefined research regulations. Calculation of incidence, prevalence and excess mortality were based on all persons who had lived in Copenhagen Municipality at some time within a 15-year period. Persons were censored at death or emigration. As the DYNAMO-HIA model uses input data stratified in 1-year age and- sex-groups and as several population strata had few observations, we smoothed out input data irregularities before they were included in the model.

*IHD and stroke:* Data on IHD (ICD-10: I20-I25) and stroke (ICD-10: I60-I69, G45) was taken from the Danish National Patient Register (LPR) on hospital contacts (Schmidt et al., 2015) and from the Cause of Death Register (Helweg-Larsen, 2011). The disease prevalence was given as the number of persons with at least one diagnosis in the period from Jan 1st 2000 to Dec 31st 2014. Incident cases were persons with a diagnosis in the period from Jan 1st 2010 to Dec 31st 2014 among persons with no diagnosis of the specific disease in the preceding ten years, and was calculated as cases per person-years at risk. Disease status was merged with mortality data, and excess mortality rates were calculated as the difference in death rates (deaths/person-years) for people with and without IHD/stroke in the period Jan 1st 2010–Dec 31st 2014.

*Diabetes:* Data on diabetes was obtained from the Danish Diabetes Register (Jørgensen et al., 2016) and included both type 1 and type 2 diabetes mellitus. The register includes information on all persons registered with diabetes in any of the relevant Danish national registers (e.g. hospitalization and prescription registers). We did not have access to diabetes data after Dec 31st 2012. The disease prevalence was given as the number of persons registered during the period Jan 1st 2000 to Dec 31st 2012. Incident cases were defined as persons with a diagnosis in the period Jan 1st 2010 to Dec 31st 2012 among persons with no diabetes diagnosis in the preceding ten years. Disease status was merged with mortality data, and excess mortality rates were calculated as the difference in death rates (deaths/person-years) for people with and without the disease in the period Jan 1st 2010 to Dec 31st 2012.

*All-cause mortality:* Date of death was obtained from the Central Personal Register for the period Jan 1st 2000 to Dec 31st 2014 (Pedersen, 2011). Death rates were given as deaths/person-years at risk.

*BMI class distribution:* Self-reported questionnaire data from the 2013 Copenhagen County Health Profile (Robinson et al., 2014) (n = 9,265, persons aged 16 + years) was used to calculate BMI (weight (kg)/height (m)$^2$). Persons were categorized as normal weight (BMI ≤ 24.9), overweight (BMI = 25–29.9) or obese (BMI ≥ 30). Among the respondents of the survey (overall response rate 52.3%), 72.3% completed the items on height and weight (Christensen et al., 2012). Weighting was done according to gender, age, socioeconomic position, ethnicity and health by Statistics Denmark.

*Risk from one disease to another disease:* We used age- and sex-specific relative risks from *meta*-analyses causally connecting diabetes to myocardial infarction (Yusuf et al., 2004) and diabetes to stroke (Barrett-Connor and Khaw, 1988) (Please see supplementary data S1 for a list of relative risks).

*Risk of disease and death from OWOB:* Data on age and sex specific relative risks from BMI classes on IHD, diabetes and stroke was obtained from peer reviewed scientific research papers, *meta*-analyses and additional material such as governmental reports collected for use in the DYNAMO-HIA database (Consortium, 2010) (See S1 for a list of relative risks).

In the future, Statistics Denmark expects proportionally more elder persons and more children living in Copenhagen Municipality (see S1 for year 2014 and 2040 population sex- and age-distributions). These projections of future population composition are based on current and past composition on gender, age, country of origin, as well as fertility, mortality and migration. Therefore, the results from the simulation models have been sex- and age-adjusted to the projected population distribution of year 2040 (men = 365,480; women = 376,650).

### 2.3. Definition of reference and counterfactual scenarios

We decided on building two counterfactual scenarios in addition to the reference scenario;

**Table 2**
Projected disease prevalence (cases per 100,000 persons) in year 2040.

| | Cases, n | | | | | | | Difference from reference scenario, n (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | IHD[1] | Diabetes[1] | Stroke[1] | IHD + stroke | IHD + diabetes | Diabetes + stroke | Diabetes + stroke + IHD | IHD[1] | | Diabetes[1] | |
| Men | | | | | | | | | | | |
| *Reference* | *3474* | *3626* | *2615* | *607* | *835* | *1375* | *744* | – | | – | |
| Obesity reduction | 3427 | 3426 | 2613 | 600 | 803 | 1311 | 721 | −48 | (−1) | −200 | (−6) |
| Eliminate obesity | 3440 | 3191 | 2660 | 597 | 731 | 1126 | 604 | −34 | (−1) | −435 | (−12) |
| **Women** | | | | | | | | | | | |
| *Reference* | *2687* | *3239* | *2715* | *454* | *715* | *873* | *443* | – | | – | |
| Obesity reduction | 2665 | 3105 | 2713 | 453 | 696 | 844 | 437 | −22 | (−1) | −134 | (−4) |
| Eliminate obesity | 2667 | 2759 | 2743 | 450 | 611 | 704 | 358 | −19 | (−1) | −480 | (−15) |

| | Difference from reference scenario, n (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Stroke[1] | | IHD + stroke | | IHD + diabetes | | Diabetes + stroke | | Diabetes + stroke + IHD | |
| Men | | | | | | | | | | |
| *Reference* | – | | – | | – | | – | | – | |
| Obesity reduction | −3 | (0) | −7 | (−1) | −32 | (−4) | −64 | (−5) | −22 | (−3) |
| Eliminate obesity | 44 | (2) | −10 | (−2) | −104 | (−12) | −249 | (−18) | −139 | (−19) |
| **Women** | | | | | | | | | | |
| *Reference* | – | | – | | – | | – | | – | |
| Obesity reduction | −3 | (0) | −1 | (0) | −19 | (−3) | −29 | (−3) | −6 | (−1) |
| Eliminate obesity | 27 | (1) | −4 | (−1) | −104 | (−15) | −169 | (−19) | −85 | (−19) |

[1] Persons with single diagnoses. IHD = Ischaemic Heart Disease.

**Table 3**
Projected life expectancy at birth (years), total and with disease, in year 2040.

| | Total LE | IHD | Diabetes | Stroke | Difference from referemce scenario, years (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total LE | | IHD | | Diabetes | | Stroke | |
| Men | | | | | | | | | | | | |
| *Reference* | *76.6* | *6.4* | *6.6* | *4.9* | – | – | – | – | – | – | – | – |
| Obesity reduction | 76.7 | 6.3 | 6.3 | 4.9 | 0.2 | (0.2) | −0.09 | (−1.4) | −0.26 | (−4.0) | −0.03 | (−0.5) |
| Eliminate obesity | 77.1 | 6.1 | 5.8 | 4.8 | 0.5 | (0.6) | −0.30 | (−4.6) | −0.82 | (−12.4) | −0.09 | (−1.9) |
| **Women** | | | | | | | | | | | | |
| *Reference* | *81.4* | *5.5* | *6.0* | *5.3* | – | – | – | – | – | – | – | – |
| Obesity reduction | 81.4 | 5.4 | 5.8 | 5.3 | 0.1 | (0.1) | −0.06 | (−1.0) | −0.18 | (−3.0) | −0.02 | (−0.5) |
| Eliminate obesity | 81.6 | 5.2 | 5.1 | 5.1 | 0.3 | (0.3) | −0.27 | (−5.0) | −0.86 | (−14.4) | −0.15 | (−2.8) |

LE = Life expectancy. IHD = Ischaemic Heart Disease.

- No change in BMI class distribution, which is referred to as reference scenario.
- Reduction in population OWOB prevalence by 25%, which is referred to as obesity reduction scenario.
- Total elimination of obesity, which is referred to as eliminate obesity scenario. (See S1 for BMI class development and BMI distribution of the three scenarios).

The transition probabilities estimated internally by DYMANO-HIA will assure that in future years the BMI class prevalence of the reference scenario according to age and sex is the same as in year 2013 (van de Kassteele et al., 2012). The two counterfactual scenarios, are gradually implemented over the period 2014–2040 and reflect partly that fewer persons get OWOB (lower transition from normal to overweight and overweight to obese), partly that persons lose weight (higher transition from obesity to overweight and from overweight to normal weight). We set the prevalence rates to be effectuated in year 2040 and let the DYNAMO-HIA calculate the yearly transition rates between BMI classes.

## 3. Results

In Copenhagen Municipality, decreasing population OWOB prevalence has potential to reduce the incidence of IHD, stroke and diabetes substantially from year 2014 to 2040 (Fig. 1a–c).

IHD, diabetes and stroke incidence rates are higher for men than for women. Among men, the incidence of IHD is expected to stagnate and incidence of stroke is expected to increase in the reference scenario but is turned into a downwards trend in the obesity reduction and eliminate obesity scenarios.

In Tables 1 and 2, estimated disease incidence rates and prevalence proportions are displayed for the reference, obesity reduction and eliminate obesity scenarios in year 2040. In absolute numbers, we find the largest effects on diabetes incidence and prevalence. Approximately 23% fewer men and 25% fewer women are estimated to have diabetes in year 2040 in the eliminate obesity scenario. Despite significant reductions in IHD and stroke incidence from reductions in obesity, incremental increases in prevalence of IHD and stroke as single standing diseases is estimated. This is likely to be ascribed to increasing life expectancy (Table 3). Multi morbidity, co-occurrence with two or more of the three diseases IHD, diabetes and stroke is common. For example, 48% of men and 39% of women with stroke are also diagnosed with IHD and/or diabetes, and the relative gains from reducing obesity are larger for multi morbidity than for any of the diseases individually. The relative effects of eliminating obesity on multi morbidity; combinations of IHD, diabetes and stroke, corresponded to an estimated 19% reduction in prevalent cases.

Large differences in life expectancy exist between men and women (Table 3). At birth, women are expected to live 4.8-years longer than men. Overall, men compared to women, can expect more years with IHD and diabetes, while women live more years with stroke which is partly explained by the steep increase in stroke with higher age. Reducing the proportion of persons with obesity not only increases the total life expectancy, but also increases disease-free life expectancy. Elimination of obesity increases life expectancy by more than three months among women and six months among men when compared with in the reference scenario.

## 4. Discussion

We simulated three scenarios of OWOB development from 2014 to 2040 and assessed the effects on life expectancy and cardiometabolic disease (IHD, diabetes and stroke) in 2040. Results were obtained by use of the DYNAMO-HIA model and we have not been able to identify other papers using dynamic simulations methods to quantify future prevalence of multi morbidity related to changes in OWOB development. Though Copenhagen Municipality has low and stable levels of OWOB, obesity is still one of the leading causes of chronic disease and reducing OWOB or eliminating obesity was estimated to reduce cardiometabolic disease incidence markedly. The results suggest that incidence of cardiometabolic disease is postponed for a subgroup of the population, and with the extended life also followed increasing disease-free life expectancy. As the risk-factor targets were reached by the end of the simulation period, and as the full health effects of changes in OWOB levels can be registered many years after these changes, expected effects of the reductions in OWOB will be larger when expanding the projection period. Incremental increase in future stroke and IHD cases was estimated, but this is partly explained by a modest increase in population life expectancy combined with higher incidence of stroke and IHD with increasing age.

We searched the literature for examples of interventions that succeeded in reducing OWOB at the population level. Despite the existence of a handful of population based multifactorial lifestyle interventions (Krogsbøll et al., 2012), they did not succeeded in reducing OWOB at the population level. Neither could the scenarios be based on OWOB levels of other countries, as Denmark has the lowest levels amongst comparable countries (Lhachimi et al., 2016). Policy led solutions, such as laws and regulations are amongst the most powerful instruments for sustainable health behavior change, with the potential to affect entire populations (Jørgensen et al., 2013). There is currently little evidence in support of a regulatory approach to addressing obesity (e.g. taxation of unhealthy food, enhancing places for physical recreation and restriction of advertising) (Jørgensen et al., 2013), but this should primarily be explained by the absence of these (Walls et al., 2011). Reasons for this reluctance to enact policy led solutions include amongst others the powerful lobby represented by the food industry (Swinburn et al., 2011). Regulation and law enforcements in many other areas, for example seat belt use, smoking and vaccinations, has resulted in important health benefits (Capewell and Capewell, 2017).

### 4.1. Study limitations and strengths

It is a strength that data on population distribution, disease and BMI class distribution originated from Copenhagen Municipality and all data on disease and mortality were from Danish nationwide registers. Information on BMI from population health surveys was weighted for non-response to reflect the distribution in the general population. Additionally, diabetes disease status was obtained by combining information from several registers, reducing the risk of differential misclassification. Advantages related to the DYNAMO-HIA model are multistate projections of disease (including multi morbidity) and mortality (Boshuizen et al., 2017). Thus, compared to more conventional forecasting models, DYNAMO-HIA takes a causal-network approach to disease development. Weaknesses regarding the simulation model are the assumption of relative risks to be stationary and other risk-factors are kept constant over time. Studies have suggested that the relative risk from obesity on health may vary over time. Azfall et al. for example find that the BMI level associated with the lowest risk of all-cause mortality has shifted from BMI 22.7 to 27.0 in the period 1976–2013 and comparable trends were observed for morbidity (Afzal et al., 2016). Period effects related to changes in clinical practice, such as improved treatments (e.g. technology offering personalized monitoring of disease status), may explain why the obesity related morbidity has decreased and this trend is likely to continue in the future (Vasan and Benjamin, 2016). On the other hand, a reduction in competing risk-factors such as smoking and air pollution may increase future deaths attributed to obesity.

## 5. Conclusions

A quantitative HIA was conducted to simulate and compare future health effects of three obesity scenarios (no change (reference), OWOB reduction, eliminate obesity) which were gradually implemented the period 2014–2040. Large reductions in cardiometabolic disease incidence and life years with diabetes is estimated as an effect of reducing OWOB. Despite isolated areas of improvement, no country has to date reversed its obesity epidemic (Svendstrup et al., 2011). The results of the study should be used as an illustration of the extent of future disease cases and life years related to OWOB, but also to motivate and present to public health planners the potential benefits from OWOB prevention.

## 6. Contributership

AMB conducted the analysis and was responsible for writing of the manuscript. KS assisted in the provision of data on BMI. AH, AMB, HBH, JS and FD were involved in the conception and design of the study. All discussed data analyses, critically revised the manuscript and approved the final version of the manuscript.

## Funding

The Danish Council for Independent Research, Medical Sciences and City of Copenhagen funded this work.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2020.101150.

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