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ORIGINAL RESEARCH

Obesity Burden and Impact of Weight Loss in Saudi Arabia: A Modelling Study

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ABSTRACT

Background: Obesity and its complications are associated with morbidity, mortality and high economic cost in Saudi Arabia. Estimating this impact at the population level and potential benefits to be gained from obesity reduction is vital to underpin policy initiatives to prevent disease risks.

Methods: We combined data in an adapted version of the value of weight loss simulation model, to predict reductions in complication rates and cost savings achievable with 15% weight loss in Saudi Arabia over 10 years. To obtain model inputs, we conducted a systematic literature review (SLR) to identify data on the prevalence of obesity and its complications in Saudi Arabia, and surveyed specialist physicians and hospital administrators in public (governmental) and private healthcare sectors. We used

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combinations of age, sex, obesity and type 2 diabetes (T2D) rates in Saudi Arabia to sample a United Kingdom (UK) cohort, creating a synthetic Saudi Arabia cohort expected to be representative of the population.
Results: The synthetic Saudi Arabia cohort reflected expected comorbidity prevalences in the population, with a higher estimated prevalence of T2D, hypertension and dyslipidaemia than the UK cohort in all age groups. For 100,000 people with body mass index 30–50 kg/m^2, it was estimated that 15% weight loss would lead to a 53.9% reduction in obstructive sleep apnoea, a 37.4% reduction in T2D and an 18.8% reduction in asthma. Estimated overall cost savings amounted to 1.026 billion Saudi Arabian Riyals; the largest contributors were reductions in T2D (30% of total cost savings for year 10), dyslipidaemia (26%) and hypertension (19%).
Conclusions: Sustained weight loss could significantly alleviate the burden of obesity-related complications in Saudi Arabia. Adopting obesity reduction as a major policy aim, and ensuring access to support and treatment should form an important part of the transformation of the healthcare system, as set out under 'Vision 2030'.

Keywords: Cost savings; Economic burden; Healthcare costs; Obesity; Overweight; Obesity-related complication; Prevalence; Saudi Arabia; Vision 2030; Weight loss

Key Summary Points

Why carry out this study?

Obesity and its complications are associated with morbidity, mortality and high economic cost in Saudi Arabia.

To quantify the potential benefits of weight loss at a population level, we estimated the impact of 15% weight loss on 10 obesity-related complications and associated costs.

What was learned from this study?

For 100,000 people with body mass index 30–50 kg/m^2, it was estimated that 15% weight loss would lead to reductions in obesity-related complications, resulting in estimated overall cost savings amounting to 1.026 billion Saudi Arabian Riyals (274 million US dollars). The greatest contributors to cost savings would be reductions in type 2 diabetes, dyslipidaemia and hypertension.

Ensuring universal access to weight management support and treatment must be considered a major policy aim in Saudi Arabia.

INTRODUCTION

Obesity is defined by the World Health Organization as "abnormal or excessive fat accumulation that presents a risk to health" [1], and is recognized as a chronic relapsing disease [2]. In the second half of the twentieth century, global obesity rates began to increase [3], and it is now estimated that 800 million people worldwide have obesity [4]. Obesity rates have risen particularly sharply in North America [5], Western Europe [6] and the Gulf region [7]. In Saudi Arabia, the Ministry of Health estimated the prevalence of overweight and obesity to be 38% and 20%, respectively, in 2019 [8]; more recently, the prevalence of obesity in Saudi Arabia has been estimated at up to 36% [9].

The clinical and economic burden of obesity stems largely from an increased risk of numerous chronic complications [10]. Apart from causing significant morbidity and mortality, these conditions often require long-term pharmacological treatment and management by specialists. Obesity is linked to a range of comorbidities, including type 2 diabetes (T2D), dyslipidaemia, hypertension and sleep apnoea, as well as respiratory and digestive conditions

[11]. Some of these conditions are of particular concern owing to their high mortality and cost burden. In 2016, the World Health Organization estimated that 3% of all deaths in Saudi Arabia were attributable to diabetes, and 37% of deaths were attributable to cardiovascular disease [12]. Within the past decade, diabetes accounted for nearly 14% of total health expenditure in Saudi Arabia [13]. A recent analysis estimating the impact of overweight and obesity on direct costs found that treatment of complications associated with excess weight amounted to 4.3% of health expenditure in Saudi Arabia in 2019, equivalent to 0.1% of gross domestic product (GDP) [14]. According to a 2020 report from the World Obesity Federation, approximately 13.6% of total healthcare expenditure in the Eastern Mediterranean region is attributable to high body mass index (BMI), and obesity resulted in an estimated 4.4% loss of GDP in Saudi Arabia in 2016 [15].

Transforming the healthcare sector in Saudi Arabia by promoting health-risk prevention, strengthening the effectiveness of services and shifting the model of care to non-communicable diseases is a key policy objective set under 'Vision 2030' [16]. Obesity control would considerably reduce costs and resource use, allowing reallocation of healthcare budgets. Therefore, assessing the actual impact of obesity in Saudi Arabia is crucial. An integrated approach to handling electronic medical records (EMRs), and widespread implementation and training by hospitals are of the utmost importance to allow such assessments [17]. Furthermore, preventing inconsistencies in the systems and coding used across different hospitals may help to streamline the collation of EMR data [18].

A recent EMR-based analysis using data from the United Kingdom (UK) Clinical Practice Research Datalink (CPRD) database estimated the effects of weight loss, relative to maintaining a stable weight, on 10 obesity-related complications (ORCs). The results showed that weight loss of 13% was associated with reductions in the risks of multiple complications: individuals in the highest class of obesity (BMI $\geq$ 40 kg/m^2) had 40% reductions in relative risks for T2D and sleep apnoea, and approximately 20% reductions for dyslipidaemia and hypertension [19]. Subsequently, the model was used as the basis for an obesity risk calculator, intended for both healthcare professionals and other users, which allows estimation of the personalized benefits of weight loss, based on an individual's clinical and demographic characteristics [20]. To estimate the economic value of weight loss on a cohort level, the individual-level risk reductions are aggregated for an EMR-based cohort in the value of weight loss simulation model and combined with treatment costs for different ORCs.

We aimed to demonstrate the potential benefits of weight loss in Saudi Arabia, in terms of both reduced complications and cost savings, using an adapted version of the value of weight loss simulation model. To overcome the limitations in the availability of real-world data in Saudi Arabia, we conducted a systematic literature review (SLR) and a micro-costing study to estimate the national clinical and economic burden of obesity. These data informed adaptation of the value of weight loss simulation model and development of a synthetic cohort, sampled from UK data, to represent the population in Saudi Arabia.

METHODS

Systematic Literature Review

To identify inputs for the value of weight loss simulation model, the SLR was carried out to collect data on the prevalence of obesity, its comorbidities and associated costs/healthcare resource use (HCRU) in the Gulf region. Following initial identification of relevant studies, the scope was narrowed to cover Saudi Arabia only.

PubMed, Embase and the abstract database of the International Federation for the Surgery of Obesity and Metabolic Disorders 23rd World Congress in 2018 were searched on 17 February 2021. Searches were designed to identify publications meeting all of the following criteria:

- Published from 2010 to 17 February 2021.

- Obesity search terms present in major indexing or reference title.
- Relevant geographical search terms present in title or abstract.
- Epidemiology, cost/economics/financial or comorbidity search terms, or search terms associated with specific named conditions of interest present.

Following the searches, titles and abstracts of the identified publications were screened to determine whether they contained relevant data on obesity prevalence, complications, costs or HCRU. A second screening round was then carried out to identify the publications that reported relevant data specifically from Saudi Arabia.

Micro-Costing Study on Cost of Complications

A micro-costing study, estimating HCRU and costs for 10 comorbidities, was used to estimate costs in both public (governmental) and private healthcare settings. Full methodological details and results from the study are published in a separate article (manuscript in preparation).

Complications and Cost Categories

The comorbidities included were aligned with those examined in the UK study estimating the effects of weight loss: T2D, heart failure, angina, hypertension, atrial fibrillation, dyslipidaemia, obstructive sleep apnoea, osteoarthritis, asthma and chronic kidney disease (CKD). These comorbidities were selected for inclusion in the original study because they represent a broad range of conditions and events associated with obesity, affecting the cardiovascular, metabolic, endocrine, musculoskeletal, respiratory and renal systems [19]. HCRU and unit costs were estimated for the following cost categories: diagnostic tests, scheduled outpatient visits, treatments received (plus dose, frequency and duration), consumables/devices, health education programmes, monitoring tests, treatment-related adverse events and complications (including inpatient, outpatient, intensive care unit and emergency room visits) and inpatient procedures.

Contributors to Micro-costing Study

HCRU estimates were obtained from 45 specialist physicians of consultant level, and unit cost estimates were obtained from 13 hospital administrators or procurement specialists. All respondents were required to have been in their current role for 3–30 years. Physicians were required to be responsible for the care of 10 or more relevant patients per month and administrators/procurement specialists were required to be knowledgeable about costs in their hospital. Potential participants were screened to ensure that they met these criteria and were selected to allow a spread of public and private settings, and different geographical regions. Online surveys were self-completed, or completed with the assistance of an interviewer, between September and October 2021.

Cost Calculations

All costs were expressed in Saudi Arabian Riyals (SAR). The cost of each item within each cost category was calculated separately. For treatment costs, averages across multiple medications and brands within each drug class were used to estimate average consumption per day and unit costs. Separate public and private cost estimates were developed. Public sector unit costs were calculated using tender prices in Saudi Arabia as a reference, and, if data for private sector unit costs were not reported in a usable form in the survey, drug costs were calculated using the prices registered by the Saudi Food and Drug Authority. SAR to United States dollar (USD) conversions were based on World Bank average official exchange rates for the year 2021 (1 USD = 3.75 SAR) [21].

Development of the Synthetic Cohort

The cohort used in the default version of the value of weight loss simulation model consists of almost 2 million individuals with an available BMI record in the Clinical Practice Research Datalink database between 2015 and 2020, with comorbidity profiles recorded at the time of the most recent BMI record. However, there are significant demographic differences between populations in Saudi Arabia and the UK, in particular the younger average age and higher T2D prevalence in Saudi Arabia. Therefore, the UK cohort was sampled to develop a synthetic Saudi Arabia cohort reflecting the characteristics of the population in Saudi Arabia, in which the impact of weight loss could be estimated more accurately.

Sources and Rationale for Demographic Estimates

Age and sex distributions for the target population were taken from the General Authority for Statistics in Saudi Arabia (2020 data) [22]. Data for age groups between 20 and 69 years were used to match the age range in the risk models.

Three sources identified in the SLR provided estimates of obesity distributions in Saudi Arabia across the BMI range of interest (27–50 kg/m^2). Memish et al. reported age and sex distributions for different BMI ranges, indicating that 23.9% of men and 33.1% of women had obesity in Saudi Arabia in 2013 [23]. Althumiri et al. reported obesity prevalences by age group and sex, based on an interview with 4709 participants. The weighted national prevalence of obesity in Saudi Arabia in 2020 was estimated as 24.7% [11]. Alfadda et al. reported data from the ACTION-IO study of obesity on the prevalence of obesity classes I (BMI 30.0–34.9 kg/m^2), II (35.0–39.9 kg/m^2) and III ($\geq$ 40 kg/m^2) [24] (Table S1).

The SAUDI-DM study reported estimated prevalences of diabetes across age and BMI categories in a representative sample of 18,034 individuals in Saudi Arabia in 2014 [25]. However, because this study was not conducted in recent years (study period: 2007–2009), and included type 1, type 2 and gestational diabetes, additional assumptions were needed to estimate the current prevalence of T2D in Saudi Arabia. In a review by Robert et al., the estimated diabetes prevalence of 25.4% in people aged 30 years or over in Saudi Arabia in 2014, taken from the SAUDI-DM study, was predicted to increase to 35.3% by 2020, a factor of 1.4 [26]. Applying the assumptions that 95% of diabetes is T2D [27] and that T2D prevalence increases equally in all age and BMI categories, a conversion factor of 1.33 was applied to the 2014 SAUDI-DM estimates to obtain estimated 2020 T2D prevalences by age and BMI (Table S2).

Generation of Synthetic Cohort

The available evidence was used to create combinations of characteristics to generate a synthetic Saudi Arabia cohort reflecting the age, sex, obesity and T2D distributions of the Saudi Arabia population. To do this, the cohort was split into age groups by sex, and the percentages of men and women in each obesity class were defined. For obesity by age group, corrections were applied to reflect the fact that obesity prevalence increases with age. T2D prevalence by age and sex was also estimated, and corrected to indicate the increase in T2D prevalence with obesity class within each age group (Tables 1, 2). Thus, it was possible to estimate how many individuals with each combination of age, sex, obesity and T2D characteristics would exist in a cohort of fixed size.

Table 1 Age and sex distribution, T2D prevalence and correction factors for obesity prevalence in the synthetic Saudi Arabia cohort

Age group (years)	Sex		T2D (%)		Obesity correction factor
	Men (%)	Women (%)	Men	Women	
20–24	6.1	5.4	12.0	9.0	0.5
25–29	7.9	6.4			
30–34	8.6	6.0	20.1	12.2	1.0
35–39	10.2	6.1			
40–44	9.3	5.3	37.0	27.9	1.2
45–49	7.1	3.6			
50–54	5.2	2.4	59.2	48.3	1.5
55–59	3.4	1.7			
60–64	2.1	1.3	66.2	58.0	1.2
65–69	1.0	0.9			
Total	61.0	39.0	–	–	–

T2D type 2 diabetes

Table 2 Obesity prevalence by sex and correction factors for T2D prevalence in the synthetic Saudi Arabia cohort

BMI group	Men (%)	Women (%)	T2D correction factor
Underweight (< 18.5 kg/m^2)	7.4	6.4	0.59
Normal weight (18.5–24.9 kg/m^2)	35.6	32.7	1.02
Overweight (25.0–29.9 kg/m^2)	33.1	27.8	1.10
Obesity class I (30.0–34.9 kg/m^2)	15.0	18.0	1.14
Obesity class II (35.0–39.9 kg/m^2)	6.3	10.4	1.16
Obesity class III (≥ 40 kg/m^2)	2.6	4.7	1.17

BMI body mass index, *T2D* type 2 diabetes

Calculation of Complication Rates and Impact of Weight Loss

The model that was originally developed to estimate the impact of weight loss on ORC rates compared the risk of developing each of 10 ORCs in a cohort with stable weight with a cohort that lost 10–25% of body weight [19]. This model included BMI, age, sex, smoking status (never/ever) and comorbidities [T2D, hypertension, dyslipidaemia and history of a cardiovascular event (transient ischaemic attack/stroke/unstable angina/myocardial infarction)] as variables. The risk engine in the value of weight loss simulation is an extension of that original model, and it estimates the impact of up to ± 20% weight change on the incidence risk of 10 ORCs [28]. The model estimates the number of incident ORC diagnoses for each demographic/obesity/T2D group in the UK population and scales the numbers according to the size of the corresponding group in the synthetic Saudi Arabia cohort (Fig. 1).

The adapted simulation model for Saudi Arabia can be used to calculate both changes in the risk of complications and changes in costs, based on inputs from the synthetic Saudi Arabia cohort and the micro-costing study, respectively. The interface allows the user to select various parameters. For this analysis, the following assumptions were used:

- Population size: 100,000.
- Sex: men and women.
- BMI range: 30–50 kg/m.^{2}
- Age range: 20–69 years.
- Provider perspective: overall, covering public plus private.
- Split of private and public costs: 28%/72%, based on published estimates [29].
- Time frame: 10 years.
- Weight change: 15% weight loss.

The model was also used to estimate overall cost savings resulting from 15% weight loss in the proportion of the population in Saudi Arabia who fall within the BMI and age ranges described above. For this analysis, the population of Saudi Arabia was assumed to be 34,810,000, based on data from the General Authority for Statistics in Saudi Arabia [22].

Compliance with Ethics Guidelines

The SLR and modelling used de-identified secondary data and the results of an SLR, and therefore did not require ethical approval or individual patient consent. Informed consent was required for participation in the micro-costings survey, as per the ESOMAR regulations. Participants were asked to provide consent for anonymised data to be included in publications, and were advised that any adverse events or product complaints raised would be reported to the relevant company.

Ethical approval for the survey was not required, according to the Rules Governing the Ethics of Scientific Research practice by King Saud University in Saudi Arabia [30], whereby ethical approval for certain types of studies is waived by the Institutional Review Board. These include studies that do not involve patients or patients' data, and those where the privacy of the participants is preserved.

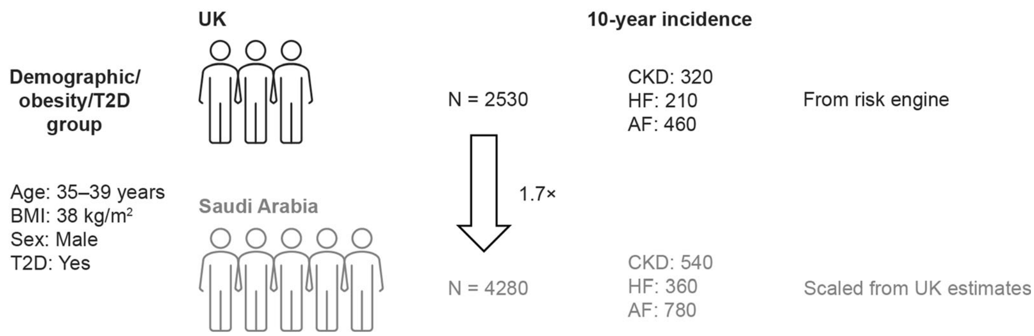

Fig. 1 Estimate of ORC incidence using the adapted value of weight loss simulation model. In the UK population, the group of men with age 35–39 years, BMI 38 kg/m^2, and T2D has 2530 individuals, and the risk engine estimates 320 incidence CKD diagnoses for this group over the coming 10 years. The corresponding group in the synthetic Saudi Arabia cohort has 4280 individuals, i.e., is 1.7-times the size of the UK group, so the expected number of incidence CKD diagnosis for this group in the Saudi Arabia cohort is $1.7 \times 320 = 540$. *AF* atrial fibrillation, *BMI* body mass index, *CKD* chronic kidney disease, *HF* heart failure, *T2D* type 2 diabetes

RESULTS

Systematic Literature Review

Initial searches identified 627 publications in PubMed, 670 additional publications in Embase and 29 publications in the International Federation for the Surgery of Obesity and Metabolic Disorders 2018 congress abstract database. Following screening, 871 publications were considered to contain potentially relevant data on obesity in the Gulf region. Data were extracted from 63 publications that reported evidence from Saudi Arabia.

Overall, 12 studies reported data on the prevalence of obesity in adults in Saudi Arabia. Smaller numbers of studies reported relevant data on hypertension, dyslipidaemia, T2D and sleep apnoea, but no identified studies reported data on other ORCs of interest. No studies reported evidence on costs or HCRU associated with obesity. Estimated costs to inform the value of weight loss simulation model were therefore derived from the micro-costing study.

Costs of Complications

The estimated costs of complications in the public and private sectors used as inputs for the risk model are shown in Table 3. Private costs were higher than public costs, with the largest disparities between private and public costs found for dyslipidaemia, osteoarthritis and T2D. The most costly complications per patient per year in the private sector were heart failure

Table 3 Estimated annual private and public costs per patient for ORCs in Saudi Arabia

Complication	Private cost per patient		Public cost per patient	
	SAR	USD	SAR	USD
Heart failure	32,020	8539	26,900	7173
CKD	22,528	6007	17,945	4785
Dyslipidaemia	26,369	7032	15,896	4239
T2D	23,271	6206	14,426	3847
Osteoarthritis	20,024	5340	10,507	2802
Sleep apnoea	15,328	4087	11,362	3030
Atrial fibrillation	15,421	4112	10,081	2688
Angina	12,652	3374	10,646	2839
Hypertension	10,693	2851	8437	2250
Asthma	10,658	2842	7121	1899

CKD chronic kidney disease, *ORC* obesity-related complication, *SAR* Saudi Arabian Riyals, *T2D* type 2 diabetes, *USD* US dollars

Table 4 Sex distributions and prevalence of ORCs in the UK and synthetic Saudi Arabia cohorts (age: 20–69 years; BMI: 30–50 kg/m^2), by age group

Age (years)	All		20–29		30–39		40–49		50–59		60–69	
	UK	Saudi Arabia	UK	Saudi Arabia	UK	Saudi Arabia	UK	Saudi Arabia	UK	Saudi Arabia	UK	Saudi Arabia
n	553,580	6,203,526	53,592	822,231	81,247	1,930,372	114,930	1,880,995	158,983	1,168,096	144,828	401,832
Sex (%)												
Women	58.5	45.4	79.5	53.7	71.9	47.1	59.1	42.9	52.7	39.8	49.3	48.3
Men	41.5	54.6	20.5	46.3	28.1	52.9	40.9	57.1	47.3	60.2	50.7	51.7
ORCs (%)												
T2D	16.2	31.8	1.3	13.4	4.6	18.1	11.0	34.1	19.5	52.5	28.7	64.5
Asthma	19.6	21.3	27.0	28.9	23.6	23.7	19.7	19.2	17.7	17.0	16.6	16.7
Sleep apnoea	3.2	3.2	0.6	1.0	1.4	2.1	2.8	3.7	4.1	5.2	4.5	5.4
Hip/knee osteoarthritis	5.0	2.2	0.1	0.1	0.3	0.3	1.7	1.5	5.2	4.9	11.7	11.4
Heart failure	1.1	0.7	0.1	0.1	0.1	0.2	0.4	0.6	1.1	1.4	2.6	3.1
CKD	4.1	2.5	0.3	0.3	0.8	1.0	1.7	2.0	3.9	4.6	9.4	10.7
Hypertension	36.6	28.6	2.6	4.6	8.8	13.0	24.1	30.3	44.7	53.7	65.8	72.7
Dyslipidaemia	29.9	26.6	0.8	3.1	4.5	10.1	15.7	27.6	35.4	53.0	60.0	73.2
Atrial fibrillation and flutter	2.1	1.0	0.1	0.1	0.2	0.3	0.6	0.7	1.9	2.0	5.5	5.4
Unstable angina/MI	2.9	1.9	0.0	0.0	0.2	0.3	1.1	1.6	3.3	4.5	6.5	7.5

BMI body mass index, *CKD* chronic kidney disease, *MI* myocardial infarction, *ORC* obesity-related complication, *T2D* type 2 diabetes

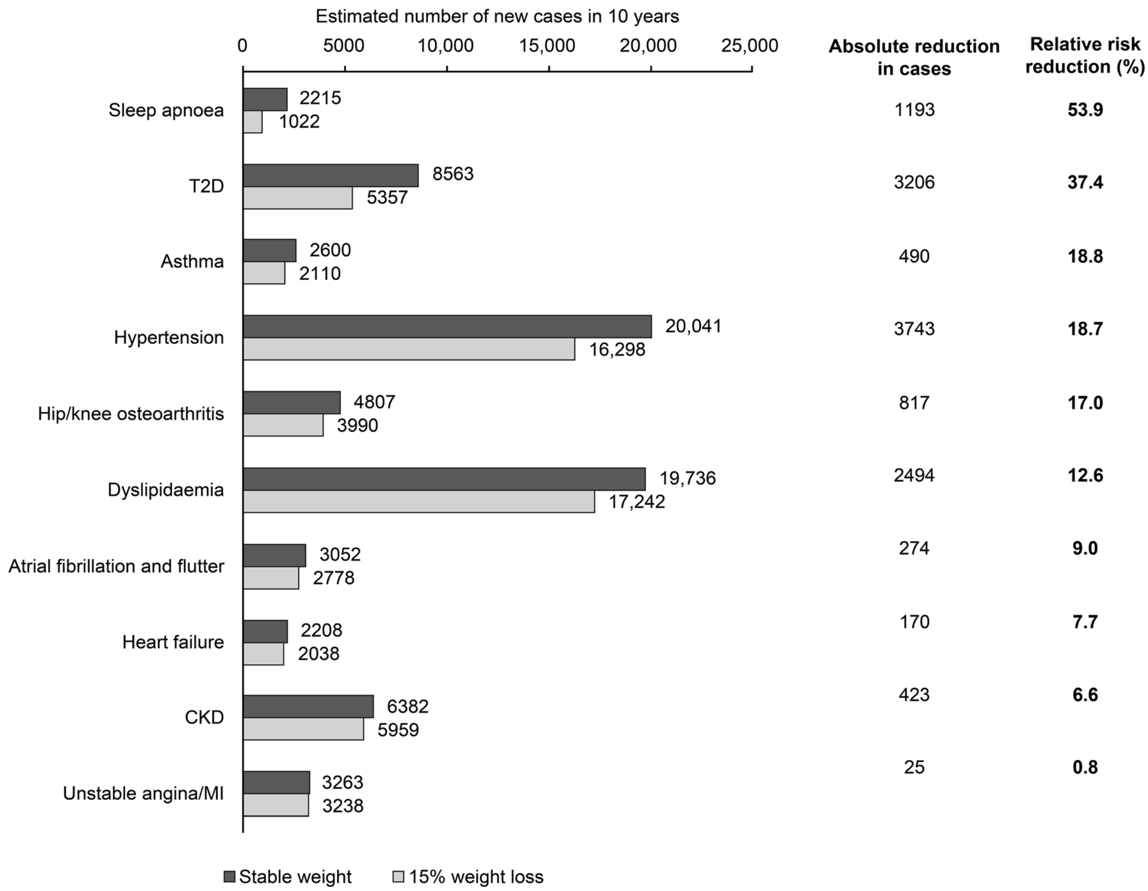

Fig. 2 Estimated impact on obesity-related complications of stable weight maintenance or 15% weight loss in a cohort of 100,000 people with obesity from the synthetic Saudi Arabia cohort. *CKD* chronic kidney disease, *MI* myocardial infarction, *T2D* type 2 diabetes

[32,020 SAR (8539 USD) per patient per year], dyslipidaemia [26,369 SAR (7032 USD)] and T2D (23,271 SAR (6206 USD)]. The most costly complications per patient per year in the public sector were heart failure [26,900 SAR (7173 USD)], CKD [17,945 SAR (4785 USD)] and dyslipidaemia [15,896 SAR (4239 USD)].

Synthetic Saudi Arabia Cohort

The synthetic Saudi Arabia cohort was assumed to include approximately 6.2 million individuals, based on published data showing that approximately 22.8 million people in Saudi Arabia are 20–69 years old [22], of whom approximately 6.2 million are assumed to have obesity, based on assumptions from studies identified in the SLR. Table 4 shows the sex distribution and prevalence of ORCs in the full UK and synthetic Saudi Arabia cohorts, and by age group in each cohort. Apart from the disparity in the prevalence of T2D, the major difference between the full cohorts was the slightly higher prevalence of asthma in the Saudi Arabia cohort. The differences between the cohorts reflect the younger age distribution in Saudi Arabia: most of the complications that were more prevalent in the UK cohort, such as osteoarthritis (5.0% vs. 2.2%), atrial fibrillation (2.1% vs. 1.0%) and CKD (4.1% vs. 2.5%), become more common with increasing age. Examining the prevalences of complications by age group overcomes the effect of this disparity and highlights the comorbidity burden in the Saudi Arabia cohort. Estimated prevalences of cardiovascular risk factors are higher in Saudi

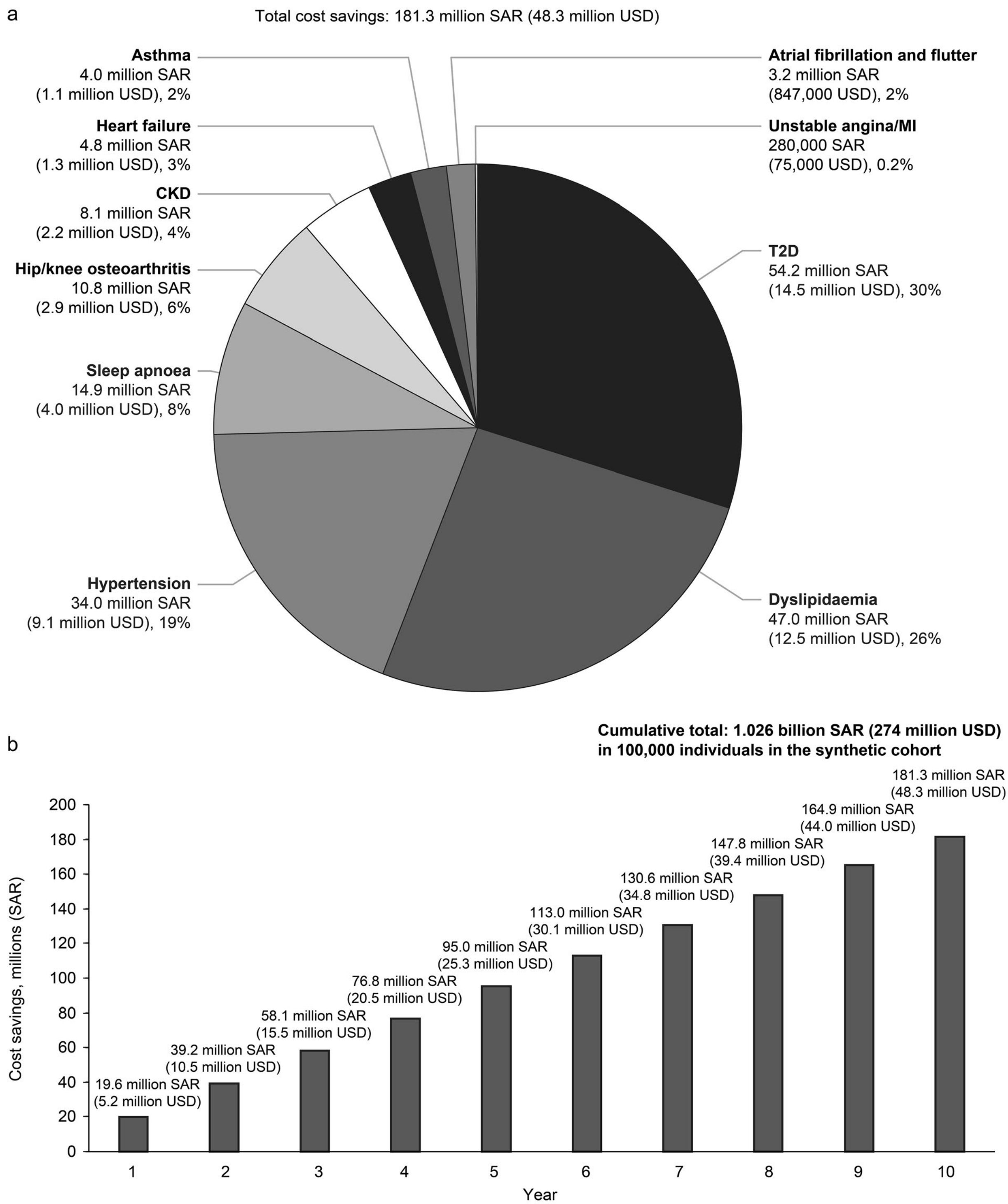

Fig. 3 Estimated cost savings achieved via 15% weight loss in a cohort of 100,000 individuals with obesity (BMI 30–50 kg/m^2) in year 10 per ORC (**a**) and over 10 years for all ORCs (**b**). *CKD* chronic kidney disease, *MI* myocardial infarction, *ORC* obesity-related complication, *SAR* Saudi Arabian Riyals, *T2D* type 2 diabetes, USD, US dollars

Arabia than in the UK for each age group; for example, for individuals aged 40–49 years, the prevalence of hypertension is 24.1% in the UK cohort and 30.3% in the Saudi Arabia cohort, and the prevalence of dyslipidaemia is 15.7% and 27.6%, respectively.

Impact of Weight Loss

The value of weight loss model estimated that, compared with maintaining stable weight, 15% weight loss in a cohort of 100,000 people with obesity in Saudi Arabia would result in a 0.8–53.9% relative reduction in the risk of ORCs (Fig. 2). The greatest estimated relative risk reductions were for sleep apnoea (53.9% reduction), T2D (37.4%), asthma (18.8%) and hypertension (18.7%).

Figure 3a shows the expected cost savings in year 10 from the reductions in each ORC following 15% weight loss. The total estimated cost savings for year 10 were 181.3 million SAR (48.3 million USD). Unsurprisingly, the greatest contributors to cost savings were conditions that were both costly and relatively common in the synthetic Saudi Arabia cohort: T2D (savings of 54.2 million SAR/14.5 million USD; 30% of total) and dyslipidaemia (47.0 million SAR/12.5 million USD; 26%). The third largest contributor to cost savings was hypertension (34.0 million SAR/9.1 million USD; 19%). Sleep apnoea had a relatively low estimated prevalence in the cohort (3.2%), but, because of its large estimated reduction in relative risk with 15% weight loss, reductions in sleep apnoea were the fourth largest contributor to cost savings (14.9 million SAR/4.0 million USD; 8%).

The overall estimated cost savings across all complications for year 1 to year 10 are shown in Fig. 3b. An annual increase in savings was predicted, in line with an increasing number of new diagnoses avoided by 15% weight loss, resulting in cumulative total cost savings of 1 billion SAR (274 million USD).

It was estimated that 6,203,526 people in Saudi Arabia fall within a BMI range of 30–50 kg/m^2 and are between 20 and 69 years old. In this group, the 10-year cumulative cost savings resulting from 15% weight loss were 63.7 billion SAR, equivalent to 17.0 billion USD.

DISCUSSION

Estimating the impact of weight loss outside a controlled setting is often challenging, particularly over the long term, as weight regain frequently follows a period of weight loss. Overall, the approach used in this study provides estimates that could not otherwise be obtained, demonstrating the prevalence of ORCs in Saudi Arabia, the costs in public and private healthcare sectors, and the potential impact of weight loss. All of these are highly relevant for individuals, society, and policy- and decision-makers.

Taken together, our results suggest that many ORCs in Saudi Arabia are highly prevalent, have a high associated cost, are strongly linked to BMI, or involve a combination of the three. T2D and dyslipidaemia were among the most common conditions, and are also among the most expensive to treat, whereas heart failure and CKD, although not highly prevalent, had a large cost impact. Heart failure, in particular, was estimated to be nearly 50% more costly to treat in the public sector than the next most expensive complication, which was CKD. Sleep apnoea and hip/knee osteoarthritis, although not among the most expensive or most prevalent conditions, were found to be associated with fairly high relative risk reductions due to weight loss; consequently, reductions in these conditions would contribute sizeable cost savings.

The robust model used in the original UK study of 13% weight loss has been widely adapted for different purposes and geographies. Whereas adaptation for countries in which the populations are expected to be demographically and clinically similar to the UK, such as other European countries, Canada or Australia, can be achieved via a simpler approach of adjusting assumptions for age, sex and BMI, adaptation to reflect the demographics of Saudi Arabia required a more complex approach. The model adaptation and sampling of the UK cohort was underpinned by a comprehensive SLR, resulting in development of a synthetic Saudi Arabia cohort that was closely aligned with the population in terms of age, sex, obesity and T2D.

In addition to sourcing relevant evidence for use in the model, the SLR also highlighted the overall lack of data available, justifying our approach. For most of the ORCs detailed in this study, no evidence was identified, meaning that the true prevalence of these conditions in Saudi Arabia is not known. No relevant data on costs or HCRU associated with obesity or its related complications were found, and therefore we carried out a micro-costing study to address this evidence gap and to obtain inputs for the model. Both public and private settings and all geographies within Saudi Arabia were represented in the survey, and detailed data were obtained on the types of HCRU and unit costs for each condition. A recent study has estimated the economic impact of ORCs in Saudi Arabia using a population attributable fraction approach, employing sex-specific risk ratios to estimate the proportions of the population affected by each ORC, but not taking into account differences in risk based on other factors, such as age or BMI [14]. Owing to limitations in data availability, the study included only six conditions: coronary heart disease, stroke, T2D, breast cancer in women, colon cancer, and asthma, and did not differentiate between public and private sectors. Sex-specific risk ratios for the included conditions were derived primarily from studies conducted in different populations in the United States of America (USA) and Europe before 2009; furthermore, risk ratios were assumed not to have changed since this time. However, despite these limitations in the generalizability of the analysis to Saudi Arabia, the results indicated a large potential cost burden. In line with our results, T2D was the greatest cost driver, accounting for 88% of direct medical costs attributable to excess weight. The analysis also estimated the costs of loss of work productivity, highlighting a sometimes overlooked impact of obesity. Together, costs associated with absenteeism and presenteeism were equivalent to 0.9% of GDP, whereas direct costs were equivalent to 0.1% of GDP [14].

Although our study addresses a number of large evidence gaps, caution must be used when interpreting our results; unlike the original UK study, our findings are not based on individual patient data, but on estimates of the impact of weight loss. Although the SLR was carefully designed to collect relevant data on ORCs, it identified several evidence gaps in the published data relating to Saudi Arabia, which contributed to some limitations in our modelling. Consequently, in developing the synthetic cohort, evidence was not available to sample the UK cohort on all relevant demographic and clinical criteria, such as the prevalence of comorbidities other than T2D. Therefore, although the synthetic Saudi Arabia cohort is similar to the population of Saudi Arabia in terms of age distribution, sex and T2D, it is likely to retain certain other characteristics that are more representative of the UK population, such as underlying factors relating to lifestyle, diet and exercise. It must also be noted that the modelling approach required the application of assumptions from different studies to calculate overall estimates for obesity and T2D prevalence; this was considered to be an acceptable approach, given the relatively small number of relevant estimates identified in the SLR. Although consideration was given to sampling a cohort from EMRs in a different population to develop the synthetic Saudi Arabia cohort, such as a population from the USA, it was concluded that the same challenges would remain and that the representativeness of the Saudi Arabia cohort would not be markedly improved. For the micro-costing study, final data were extrapolated from a sample of private and public hospitals in Saudi Arabia, and therefore might not have captured some of the disparities across different treatment centres. Furthermore, as the cost estimates in our study are based on a hypothetical population with set age and BMI ranges, they cannot be scaled to estimate the economic impact of obesity or the cost savings associated with weight loss in the entire population of Saudi Arabia. Altogether, our data represent the best available estimates for the clinical and economic impacts of obesity in Saudi Arabia, but future real-world studies to track population rates of obesity complications and HCRU are still a high priority.

CONCLUSIONS

The results of our study indicate the need for support with weight management programmes in Saudi Arabia. We have demonstrated the burden of obesity in terms of its direct impacts on individuals and healthcare systems, and these are also expected to lead to additional effects not captured in this study, such as indirect costs, productivity loss and decreased health-related quality of life. Our findings also show that sustained weight loss can significantly alleviate this burden, with large cost savings resulting from reductions in ORCs. Therefore, if the obesity epidemic is to be halted and ultimately reversed, ensuring universal access to weight management support and treatment must be considered a major policy aim in Saudi Arabia.

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Disclosures. Ali Alshehri has provided consultancy to Novo Nordisk. Abdulmohsen Abanumay and Mahmoud S. Eldin are employees of Novo Nordisk, Saudi Arabia. Volker Schnecke is an employee of Novo Nordisk A/S. Saleh A. Alqahtani, Hussain A. Al-Omar, Hana Alabdulkarim and Ali Alrumaih have nothing to disclose.

Compliance with Ethics Guidelines. The SLR and modelling used de-identified secondary data and the results of an SLR, and therefore did not require ethical approval or individual patient consent. Informed consent was required for participation in the micro-costings survey, as per the ESOMAR regulations. Participants were asked to provide consent for anonymized data to be included in publications, and were advised that any adverse events or product complaints raised would be reported to the relevant company. Ethical approval for the survey was not required, according to the Rules Governing the Ethics of Scientific Research practice by King Saud University in Saudi Arabia [30], whereby ethical approval for certain types of studies is waived by the Institutional Review Board. These include studies that do not involve patients or patients' data, and those where the privacy of the participants is preserved.

Data Availability. All data generated or analysed during this study are included in this published article/as supplementary information files, or have been submitted for publication separately.

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