Health-care spending attributable to modifiable risk factors in the USA: an economic attribution analysis

Howard J Bolnick, Anthony L Bui, Anne Bulchis, Carina Chen, Abigail Chapin, Liya Lomsadze, Ali H Mokdad, Francois Millard, Joseph L Dieleman

Summary

Background There is a robust understanding of how specific behavioural, metabolic, and environmental risk factors increase the risk of health burden. However, there is less understanding of how these risks individually and jointly affect health-care spending. The objective of this study was to quantify health-care spending attributable to modifiable risk factors in the USA for 2016.

Methods We extracted estimates of US health-care spending by condition, age, and sex from the Institute for Health Metrics and Evaluation's Disease Expenditure Study 2016 and merged these estimates with population attributable fraction estimates for 84 modifiable risk factors from the Global Burden of Diseases, Injuries, and Risk Factors Study 2017 to produce estimates of spending by condition attributable to these risk factors. Because not all spending can be linked to health burden, we adjusted attributable spending estimates downwards, proportional to the association between health burden and health-care spending across time and age for each aggregate health condition. We propagated underlying uncertainty from the original data sources by randomly pairing the draws from the two studies and completing our analysis 1000 times independently.

Findings In 2016, US health-care spending attributable to modifiable risk factors was US$730·4 billion (95% uncertainty interval [UI] 694·6–768·5), corresponding to 27·0% (95% UI 25·7–28·4) of total health-care spending. Attributable spending was largely due to five risk factors: high body-mass index ($238·5 billion, 178·2–291·6), high systolic blood pressure ($179·9 billion, 164·5–196·0), high fasting plasma glucose ($171·9 billion, 154·8–191·9), dietary risks ($143·6 billion, 130·3–156·1), and tobacco smoke ($130·0 billion, 116·8–143·5). Spending attributable to risk factor varied by age and sex, with the fraction of attributable spending largest for those aged 65 years and older (45·5%, 44·2–46·8).

Interpretation This study shows high spending on health care attributable to modifiable risk factors and highlights the need for preventing and controlling risk exposure. These attributable spending estimates can contribute to informed development and implementation of programmes to reduce risk exposure, their health burden, and health-care cost.

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Vitality Group, Chicago, IL, USA (H J Bolnick FSA, F Millard FSA); **Department of Pediatrics, University of Washington, Seattle Children's Hospital, Seattle, WA, USA** (A L Bui MD); **Institute for Global Health Sciences, University of California, San Francisco, CA, USA** (A Bulchis MPH); **and Institute for Health Metrics and Evaluation, Seattle, WA, USA** (C Chen MA, A Chapin BA, L Lomsadze BS, A H Mokdad PhD, J L Dieleman PhD)

Correspondence to: Joseph Dieleman, Institute for Health Metrics and Evaluation, Seattle, WA 98121, USA **dieleman@uw.edu**

Introduction

Evidence connecting exposure to risk factors and adverse health outcomes has long been used to support the development of public policy and public health promotion and prevention programmes. The US Centers for Disease Control and Prevention has recognised public health programmes that reduced deaths from coronary heart disease and stroke and prevented deaths from smoking as two of the greatest public health achievements of the 20th century, both championed by robust evidence connecting these risks to reductions in healthy life expectancy.[1] More recently, the private sector in some countries, including employers, health insurance companies, and health promotion companies, has been developing programmes to improve individuals' health and control health-care spending.[2–7]

Although there is a large volume of epidemiology research exploring the causal roles connecting a wide range of behavioural, metabolic, and environmental risk factors and health outcomes, there has been much less research assessing the role that risk factors have on health-care spending. Moreover, studies to date have generally focused on a single risk factor or disease. To our knowledge, no study links a comprehensive set of modifiable risk factors to health-care spending by condition.

To address this research gap, we estimated US health-care spending attributable to 84 modifiable risk factors in 2016, with the latest data available. We included behavioural risks, such as tobacco use and dietary risks; metabolic risks, such as high body-mass index (BMI) and high blood pressure; and environmental risks, such as air pollution and occupational carcinogens. Knowledge of health-care spending attributable to modifiable risk factors can inform choices and priorities for the design of public and private health promotion and prevention programmes, both in the USA and elsewhere.

Research in context

Evidence before this study

We searched PubMed and Google Scholar in June, 2020, for studies attributing health-care spending and health outcomes to a broad set of modifiable risk factors. There is a great deal of epidemiological research estimating the relationship between exposure to key modifiable risk factors and health outcomes. The 2017 Global Burden of Diseases, Injuries, and Risk Factors Study (GBD), one of the largest of such studies, shows that nearly 50% of health burden globally (measured using disability-adjusted life-years) can be attributed to a set of 84 modifiable risk factors. In the USA, risk factors with the most attributable health burden in 2017 were high body-mass index (BMI) and smoking. The Disease Expenditure Project at the Institute for Health Metrics and Evaluation estimated that in 2016, 72% of personal health-care spending was for non-communicable diseases. Health conditions with the most spending were low back and neck pain, other musculoskeletal disorders, and diabetes. Despite comprehensive studies tracking health burden, attributable health burden, and health-care spending across a broad set of health conditions, most studies assessing health-care spending attributable to risk exposure focus on a single health condition or risk factor. Previous research has estimated health-care spending attributable to key risks such as hypertension, tobacco use, and physical inactivity. Importantly, these individual studies are generally not comparable as they apply different methods, assumptions, and the risk of double counting attributable spending, and consequently, as far as we are aware, there is no information available about estimating attributable health-care spending across a comprehensive set of health conditions considering a similarly large set of modifiable risk factors.

Added value of this study

This study builds from estimates generated for GBD 2017 regarding 84 modifiable risk factors and the Disease Expenditure Project, which measures annual health-care spending by age, sex, type of care, payer, and health condition, between 1996 and 2016. With these inputs, we estimated health-care spending individually and jointly attributable to 84 modifiable risks. This study highlights that 27·0% of personal health-care spending in the USA in 2016 can be attributable to this broad set of risk factors, with most spending attributable to high BMI, high systolic blood pressure, high fasting plasma glucose, dietary risks, and tobacco smoke.

Implications of all the available evidence

With these estimates, policy makers, health programme administrators, and public health advocates can be better informed about relationships between exposures to key risks and health-care spending and better able to target public and private programmes to improve health and control increases in health-care spending. These estimates provide important information that can be used to more effectively design health promotion and prevention programmes in the USA and elsewhere. Moreover, the methods applied here can be a template for other countries, in efforts to quantify comprehensively the cost of key risks related to obesity, tobacco use, and physical inactivity.

Methods

Framework

We estimated health-care spending attributable to modifiable risk factors (henceforth referred to as attributable spending) using a simple two-step process using data from two existing studies. The first dataset was from the Institute for Health Metrics and Evaluation's Disease Expenditure Project, from which we extracted estimates of how much was spent on health care for 154 mutually exhaustive health conditions by age group and sex in 2016 in the USA.[8–12] The second dataset was from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2017, from which we extracted health condition-specific estimates of health burden—number of deaths, years lived with disability (YLDs), and disability-adjusted life-years (DALYs)—and the estimated population attributable fractions for 84 modifiable risk factors, for each health condition, age, and sex group in 2016.[13–17] Population attributable fractions measure the portion of health burden for each health condition that is attributable to each risk factor based on the relative risks associated with risk exposures and actual risk exposure in the population.

The first step for measuring attributable spending was to estimate the amount of health-care spending associated with health burden. We did this by multiplying health-care spending by the Pearson correlation coefficient between health burden and health-care spending. In simple terms, this coefficient measures to what degree health burden and health-care spending are correlated. The second step was to estimate how much of this health-care spending was attributable to modifiable risk factors. We did this by multiplying the product from the first step by the population attributable fraction for each risk factor. We estimated attributable spending separately for 38 age and sex groups, 154 health conditions, and 84 risk factors.

The intuition of this two-step process is that population attributable fractions estimate the fraction of health burden attributable to the included modifiable risk factors, while the correlation coefficient between health-care spending and health burden approximates the fraction of health-care spending that is associated with health burden. Collectively, this two-step process—ultimately the product of the population attributable fraction, the correlation coefficient, and health-care spending—generates an estimate of health-care spending attributable to the included risk factors for each health condition and age and sex group.

Data sources

We extracted population attributable fractions from GBD 2017,[18] which assessed health burden for 195 countries from 1990 to 2017. In addition, GBD 2017 measured the portion of the health burden for each health condition that is attributable to 84 modifiable risk factors, for each age and sex group. Population attributable fractions were measured for every health condition and risk factor pair. More than 463 data sources were used to make these estimates. Population attributable fractions are described more fully in the appendix (pp 3–6) and previous literature.[14] For this study, we used estimates for 2016.

The 84 risk factors included in this study are organised using a hierarchy. The most aggregated level of the hierarchy included all risk factors (level 0). Level 1 consisted of three groups: all metabolic risks, all behavioural risks, and all environmental risks. At the most granular level, behavioural risks comprise 35 individual risk factors, including dietary risks, tobacco use, and alcohol and drug use. Metabolic risks comprise six individual risk factors, including high BMI, high fasting plasma glucose, and high blood pressure. Environmental risks comprise 26 individual risks, including air pollution, occupational carcinogens, and occupational injury. For interpretability, we report results for risk factor level 2, of which there are 19. The complete list of risk factors and their hierarchy level is included in the appendix (pp 4–5). These 84 risk factors were chosen for GBD according to relevance to public health and policy, data availability, and epidemiological evidence of a causal connection between risk exposure and health burden.

GBD 2017 measured the attribution of health burden and premature death for each individual risk factor. Some risk factors included in this study are mitigating factors of other risk factors also included in the study, meaning that one risk could contribute, exacerbate, or mitigate the effect of another risk, such as low physical activity contributing to effect of high fasting plasma glucose. As a result of this risk factor connectedness, attributable spending estimates for individual risk factors cannot be aggregated. To report spending estimates across multiple risk factors, including estimates for all behavioural risks or all risks, GBD estimated so-called joint population attributable fractions for each level of the risk factor hierarchy. These joint population attributable fractions were estimated by multiplicative aggregation of population attributable fractions for individual risk factors using a competing risk probability model while adjusting for risk mediation. Joint population attributable fractions avoid the double counting that would occur if one simply aggregated population attributable fractions for individual risk factors.

We extracted health condition-specific health-care spending estimates from the Disease Expenditure 2016 study.[8] This study split health-care spending, which includes spending on ambulatory, inpatient, emergency department, dental, and nursing facility care and prescribed pharmaceuticals, into 154 health conditions and 38 age and sex groups. The study was built from 183 data sources, including private and public insurance claims data, health-care providers' administrative data, and household surveys. Spending estimates were adjusted and combined to estimate all personal health-care spending in these settings and to adjust for the presence of comorbidities. Estimates are reported in 2016 US dollars. While the Disease Expenditure 2016 study tracks annual spending for 1996 to 2016, only spending information for 2016 was used. More information about this study and these adjustments is provided in the appendix (pp 2–3) and in previously published materials.[8,13,16,17,19]

See Online for appendix

Estimating attributable spending

To estimate the fraction of health-care spending attributable to ill health, we adjusted health-care spending by multiplying it by the Pearson correlation coefficient between health burden and health-care spending. These coefficients were calculated for each aggregate health condition category, such as cardiovascular diseases or cancers, and for three measurements of health burden: deaths, YLDs, and DALYs. The correlation coefficients report the share of spending that was positively correlated with health burden. The product of the largest of the three correlation coefficients and the health-care spending was our estimated fraction attributable to ill health.

To estimate attributable spending for each modifiable risk factor, we multiplied the health-care spending attributable to ill health for each health condition by the population attributable fraction for each risk factor and that health condition. This procedure was done for each risk factor (and joint risk factor) and each health condition, and for each of the 38 age and sex groups. The appendix reports the population attributable fraction metric used for each health condition and the corresponding correlation coefficient, as well as a detailed example showing how attributable spending for ischaemic heart disease was calculated (pp 8–9).

Uncertainty

Uncertainty intervals (UIs) for the data extracted for this study were calculated in GBD and the Disease Expenditure Project using 1000 independent draws. To propagate this underlying uncertainty, we randomly paired the draws from the two studies and completed our analysis 1000 times, including the adjustment of the population attributable fractions, independently. We present mean estimates with 95% UIs generated by the 2·5th and 97·5th percentiles. All analyses were done using R (version 3.6.3).

Reporting

For reporting purposes, we aggregated the 38 age and sex groups into four aggregated age categories and the 154 health conditions into 14 aggregated categories. The aggregated category of well care consists of health care

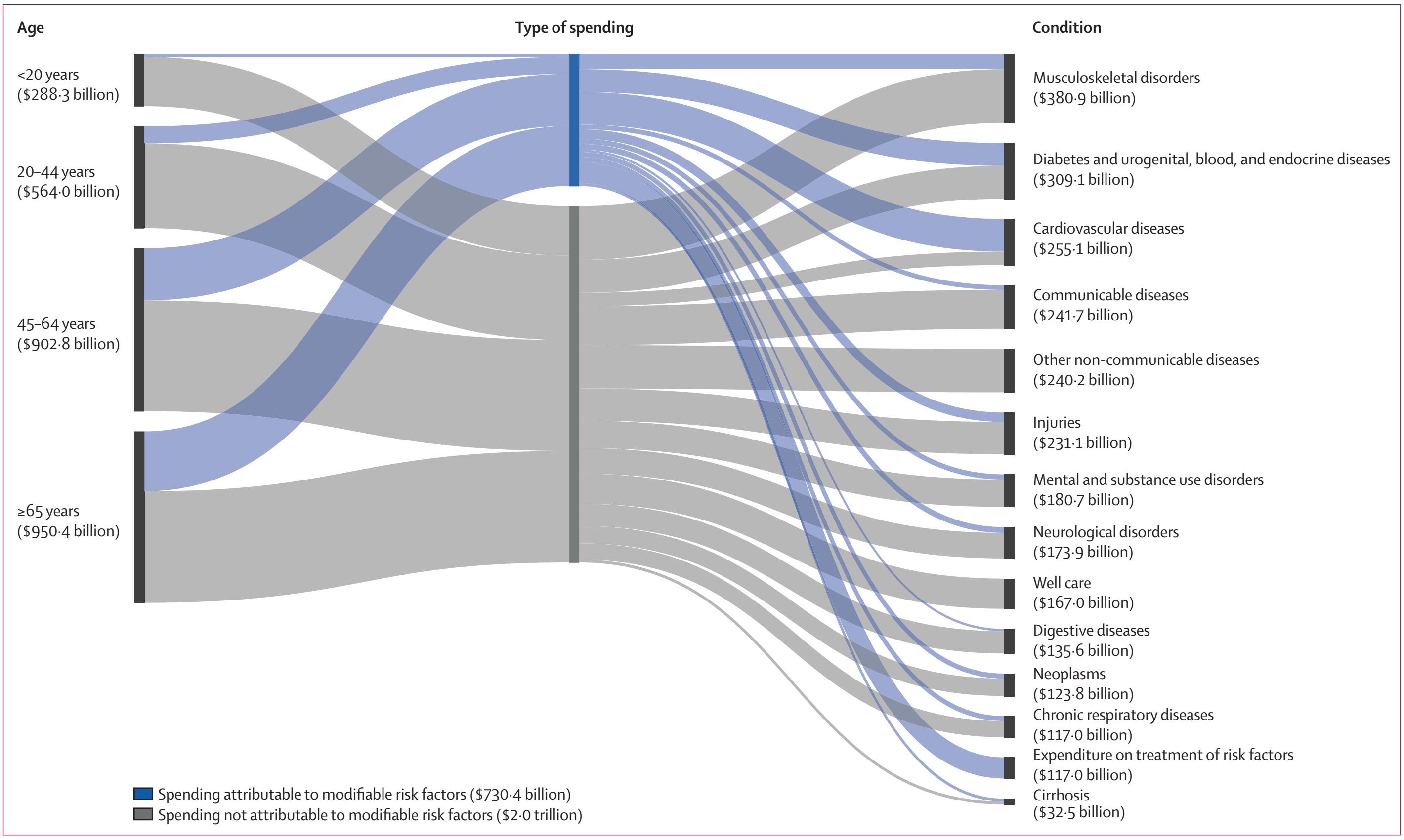

Figure 1: **Spending by age, spending attribution, and aggregated condition category, 2016**
Health-care spending is measured in 2016 US dollars.

that is for health conditions that are not associated with health burden, such as the cost of labour and delivery or preventive dental care. Treatment of risk factors is spending on four specific risk factors: hypertension, hyperlipidaemia, smoking, and obesity. All estimates are repored in 2016 US dollars.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all of the data in the study and had final responsibility for the decision to submit for publication.

Results

In 2016, we estimated that US$730·4 billion (95% UI 694·6–768·5), or 27·0% (95% UI 25·7–28·4) of total US health-care spending (included in the Disease Expenditure Project), was attributable to the modifiable risk factors included in this study. Attributable spending is largely associated with older ages (ie, ≥45 years) and chronic conditions such as cardiovascular diseases; diabetes and urogenital, blood, and endocrine diseases; and management of metabolic risks, which includes treatment of hypertension and hyperlipidaemia (figure 1).

High BMI had the most attributable spending in 2016, at $238·5 billion (95% UI 178·2–291·6; figure 2A). 33·2% (95% UI 29·5–37·2) of this attributable spending was on diabetes and urogenital, blood, and endocrine diseases and 26·0% (23·4–28·5) was on cardiovascular diseases.

High systolic blood pressure was the risk factor with the second-highest attributable spending, at $179·9 billion (95% UI 164·5–196·0; figure 2A). Of this spending, 50·4% (95% UI 45·8–54·6) was for cardiovascular diseases, 43·9% (39·9–48·4) for expenditure on hypertension management, and 5·7% (4·5–6·9) for diabetes and urogenital, blood, and endocrine diseases.

High fasting plasma glucose was the risk factor with the third-highest attributable spending, at $171·9 billion (95% UI 154·8–191·9; figure 2A). Of this spending, 70·2% (95% UI 63·2–76·9) was for diabetes and urogenital, blood, and endocrine diseases; 23·6% (18·1–30·3) for cardiovascular diseases; and 4·7% (1·1–10·0) for neurological disorders.

Dietary risks was the risk factor with the fourth-highest amount of attributable spending, at $143·6 billion (95% UI 130·3–156·1; figure 2A). Among the 14 components of dietary risks, diet low in whole grains, diet low in fruits, and diet low in nuts and seeds were the three largest sources of spending (data not shown). The

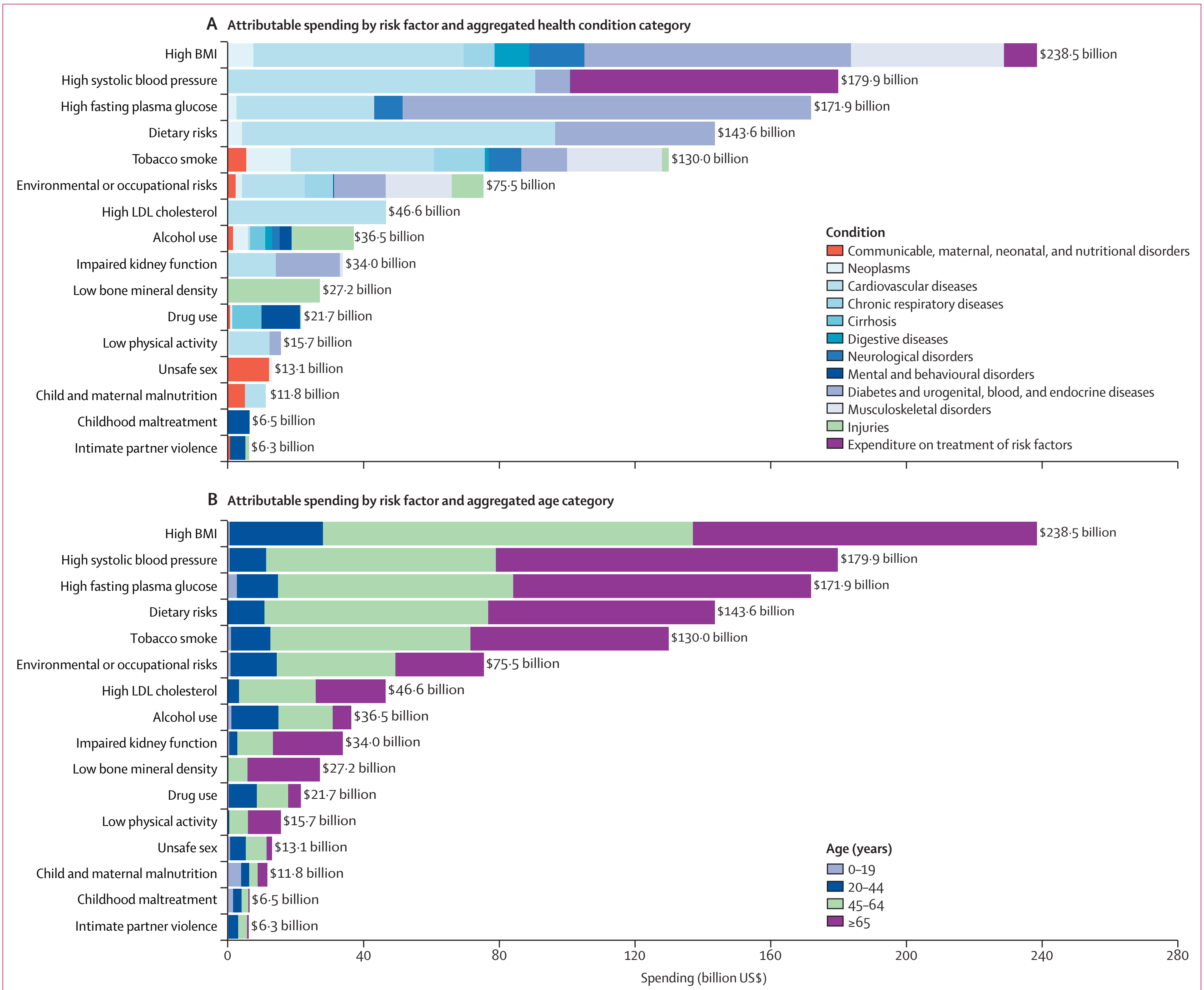

Figure 2: **Health-care spending attributable to risk factor categories by aggregated health condition (A) and age group (B), 2016**
Health-care spending is measured in 2016 US dollars. Due to risk interaction and mediation, attributable spending by risk category does not sum up to total attributable spending. BMI=body-mass index.

majority (64·3%, 95% UI 59·3–69·1) of this spending was for cardiovascular diseases, with 32·8% (28·3–37·4) on diabetes and urogenital, blood, and endocrine diseases (figure 2A).

Tobacco smoke had the fifth-highest attributable spending, at $130·0 billion (95% UI 116·8–143·5; figure 2A). Of spending attributable to tobacco smoke, 32·6% (95% UI 29·9–35·4) was for cardiovascular diseases and 21·4% (17·6–25·1) was for musculoskeletal disorders.

At an aggregated risk level (level 1), metabolic risks, which included high systolic blood pressure, high fasting plasma glucose, and high BMI, were associated with the greatest attributable spending, at $508·0 billion (95% UI 468·9–549·1) in 2016. Behavioural risks, including dietary risks and tobacco smoke, had the second-highest attributable spending, at $349·4 billion (329·1–369·6). Finally, $75·5 billion (62·0–89·5) of spending was attributed to environmental risks.

Spending attributable to modifiable risk factors was largely for non-communicable diseases (table). The aggregated health category with the greatest attributable spending was cardiovascular diseases, which included ischaemic heart disease and cerebrovascular disease. In 2016, total spending on these diseases was $255·1 billion (95% UI 233·4–282·6), while attributable spending was $180·7 billion ($168·0–192·8) or 70·9% (95% UI 65·2–

74·4) of the total. The largest risk factors for ischaemic heart disease were dietary risks, high systolic blood pressure, and high total cholesterol. Risk factors associated with cerebrovascular disease were high systolic blood pressure, dietary risks, and high BMI (data not shown).

The category with the second-highest attributable spending was diabetes and urogenital, blood, and endocrine diseases, at $126·3 billion (95% UI 118·3–133·5) in 2016 (table). Attributable spending in this category was mainly for diabetes, with $107·4 billion (101·9–112·0), and chronic kidney diseases, with $19·0 billion (15·7–22·2). The risk factors most associated with diabetes spending were high fasting plasma glucose, high BMI, and dietary risks.

The treatment of four risk factors—high blood pressure, cholesterol, glucose and obesity—was the aggregated health category with the third-highest attributable spending, at $117·0 billion (95% UI 109·3–125·7). The greatest spending was for treatment of hypertension and hyperlipidaemia, with substantially less spent on treating obesity and tobacco cessation. The spending included in this category was specific to the treatment of these risk factors, not spending on diseases caused by them, so all spending was considered attributable to risk factors (table).

	Total spending	Spending by age group				Spending by sex	
		0–19 years	20–44 years	45–64 years	≥65 years	Female	Male
All conditions							
Total spending	$2705·6 (2705·6–2705·6)	$288·3 (274·8–300·9)	$564·0 (552·0–576·1)	$902·8 (888·4–916·6)	$950·4 (935·3–966·1)	$1563·0 (1542·2–1582·6)	$1142·6 (1123·0–1163·4)
Attributable spending	$730·4 (694·6–768·5)	$14·7 (13·4–16·6)	$94·6 (88·9–100·3)	$289·0 (275·0–302·5)	$332·1 (310·8–355·6)	$377·2 (354·0–400·4)	$353·2 (336·9–371·9)
Percentage of total	27·0% (25·7–28·4)	5·1% (4·6–5·7)	16·8% (15·8–17·6)	32·0% (30·6–33·5)	34·9% (32·8–37·3)	24·1% (22·8–25·5)	30·9% (29·5–32·6)
Cardiovascular diseases							
Total spending	$255·1 (233·4–282·6)	$4·3 (3·7–5·1)	$16·0 (14·6–17·7)	$83·0 (73·6–97·5)	$151·8 (137·2–166·7)	$119·1 (110·2–127·2)	$136·0 (121·4–161·1)
Attributable spending	$180·7 (168·0–192·8)	$1·6 (1·4–1·9)	$10·8 (9·7–11·8)	$63·9 (57·9–70·4)	$104·5 (96·7–112·4)	$82·1 (74·8–88·4)	$98·5 (90·6–107·9)
Percentage of total	70·9% (65·2–74·4)	37·3% (31·6–42·1)	67·3% (63·0–71·0)	77·1% (68·9–81·2)	68·9% (63·7–72·7)	69·0% (65·9–71·9)	72·7% (64·1–77·2)
Diabetes and urogenital, blood, and endocrine diseases							
Total spending	$309·1 (292·4–328·4)	$14·0 (12·7–15·9)	$54·2 (51·2–57·4)	$123·4 (115·3–132·6)	$117·5 (109·6–126·3)	$181·5 (172·2–192·3)	$127·6 (116·6–140·6)
Attributable spending	$126·3 (118·3–133·5)	$3·3 (2·5–5·1)	$12·7 (11·2–14·0)	$57·5 (53·3–60·9)	$52·9 (48·8–57·2)	$64·5 (60·5–68·8)	$61·9 (56·1–67·6)
Percentage of total	40·9% (39·2–42·2)	23·2% (18·7–32·2)	23·4% (21·5–25·1)	46·6% (43·9–48·9)	45·0% (42·4–48·0)	35·5% (34·1–37·2)	48·5% (44·8–51·7)
Expenditure on treatment of risk factors							
Total spending	$117·0 (109·3–125·7)	$0·9 (0·8–1·3)	$12·0 (10·6–13·6)	$48·9 (45·0–52·6)	$55·1 (50·6–61·2)	$63·7 (58·8–70·0)	$53·3 (47·9–59·1)
Attributable spending	$117·0 (109·3–125·7)	$0·9 (0·8–1·3)	$12·0 (10·6–13·6)	$48·9 (45·0–52·6)	$55·1 (50·6–61·2)	$63·7 (58·8–70·0)	$53·3 (47·9–59·1)
Percentage of total	100·0% (100·0–100·0)	100·0% (100·0–100·0)	100·0% (100·0–100·0)	100·0% (100·0–100·0)	100·0% (100·0–100·0)	100·0% (100·0–100·0)	100·0% (100·0–100·0)
Musculoskeletal disorders							
Total spending	$380·9 (360·0–405·4)	$13·6 (12·1–15·6)	$64·6 (58·4–70·7)	$168·8 (159·1–179·3)	$133·9 (124·6–146·4)	$232·8 (214·7–251·9)	$148·1 (137·9–158·3)
Attributable spending	$83·2 (66·8–99·1)	$0·1 (0·1–0·2)	$13·2 (10·9–15·5)	$43·2 (35·2–50·9)	$26·7 (19·6–34·4)	$46·8 (36·0–57·9)	$36·4 (29·3–43·6)
Percentage of total	21·9% (17·8–25·9)	0·9% (0·6–1·1)	20·4% (17·3–23·5)	25·6% (21·2–29·9)	20·0% (14·7–25·3)	20·1% (15·7–24·5)	24·6% (19·9–28·8)
Injuries							
Total spending	$231·1 (211·7–250·7)	$23·0 (20·7–25·9)	$57·2 (51·4–63·1)	$76·4 (68·0–85·7)	$74·5 (64·3–84·6)	$115·7 (102·7–128·1)	$115·4 (104·5–126·1)
Attributable spending	$52·5 (44·8–61·0)	$1·2 (0·9–1·6)	$11·6 (9·4–14·2)	$15·1 (11·9–18·9)	$24·6 (21·2–28·4)	$27·7 (23·8–32·1)	$24·8 (20·2–30·2)
Percentage of total	22·7% (19·7–26·2)	5·3% (4·0–6·8)	20·3% (17·0–24·1)	19·8% (16·4–24·0)	33·0% (29·3–37·1)	24·0% (21·0–27·2)	21·4% (18·2–25·2)

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	Total spending	Spending by age group				Spending by sex	
		0–19 years	20–44 years	45–64 years	≥65 years	Female	Male
(Continued from previous page)							
Neurological disorders							
Total spending	$173·9 (161·2–186·9)	$8·2 (6·9–10·0)	$21·5 (19·5–23·9)	$41·7 (37·4–45·9)	$102·5 (91·0–113·7)	$113·1 (103·4–123·9)	$60·8 (55·1–68·1)
Attributable spending	$31·8 (20·8–44·4)	$0·1 (0·1–0·2)	$1·5 (1·2–1·9)	$2·4 (1·9–3·0)	$27·7 (16·7–40·1)	$20·4 (11·3–30·4)	$11·4 (7·4–16·2)
Percentage of total	18·3% (11·9–25·1)	1·3% (0·7–2·0)	7·2% (5·4–8·9)	5·9% (4·6–7·4)	27·0% (16·7–37·9)	18·0% (10·1–26·5)	18·8% (12·4–26·1)
Mental and substance use disorders							
Total spending	$180·7 (172·8–189·7)	$26·6 (23·7–30·6)	$65·4 (60·5–69·7)	$64·3 (60·9–68·1)	$24·5 (22·0–27·0)	$107·9 (100·3–115·5)	$72·7 (67·6–77·8)
Attributable spending	$28·9 (25·9–31·9)	$2·4 (1·8–3·2)	$12·6 (10·9–14·3)	$10·6 (9·4–12·0)	$3·3 (2·6–3·9)	$15·5 (13·5–17·6)	$13·4 (11·7–15·0)
Percentage of total	16·0% (14·6–17·5)	9·0% (6·9–11·5)	19·3% (17·1–21·5)	16·6% (14·5–18·7)	13·5% (10·9–16·2)	14·4% (12·6–16·2)	18·5% (16·5–20·3)
Neoplasms							
Total spending	$123·8 (114·9–132·8)	$8·3 (7·4–9·3)	$18·8 (17·6–20·5)	$47·7 (43·4–52·5)	$49·0 (44·3–53·0)	$62·9 (57·5–68·2)	$60·9 (56·5–66·2)
Attributable spending	$27·8 (24·4–31·6)	$0·1 (0·0–0·1)	$3·0 (2·5–3·6)	$12·7 (10·9–14·6)	$12·1 (10·6–13·8)	$12·9 (11·2–14·7)	$14·9 (13·0–17·0)
Percentage of total	22·5% (20·1–25·1)	0·6% (0·5–0·8)	15·9% (13·5–18·6)	26·6% (23·7–29·7)	24·7% (21·6–27·9)	20·5% (17·9–23·4)	24·5% (21·9–27·1)
Chronic respiratory diseases							
Total spending	$117·0 (110·8–123·2)	$18·3 (16·1–20·9)	$19·4 (17·2–21·6)	$40·1 (37·1–43·1)	$39·3 (36·4–42·5)	$70·7 (65·9–75·9)	$46·4 (42·4–50·8)
Attributable spending	$27·2 (23·2–31·6)	$0·6 (0·4–0·9)	$3·2 (2·5–4·0)	$10·6 (8·9–12·4)	$12·8 (10·7–15·1)	$16·0 (13·3–19·0)	$11·2 (9·4–13·2)
Percentage of total	23·3% (19·7–27·1)	3·2% (1·9–4·8)	16·6% (12·6–21·5)	26·5% (22·4–31·2)	32·6% (28·4–36·8)	22·6% (18·7–27·3)	24·2% (20·8–28·2)
Communicable, maternal, neonatal, and nutritional diseases							
Total spending	$241·7 (226·5–258·6)	$70·9 (63·9–81·7)	$61·3 (56·9–65·5)	$53·9 (47·8–61·3)	$55·5 (50·6–60·1)	$139·1 (130·5–147·9)	$102·6 (94·4–113·5)
Attributable spending	$25·9 (20·9–32·0)	$4·4 (3·8–5·1)	$6·3 (5·3–7·6)	$9·7 (7·0–12·8)	$5·5 (3·8–7·8)	$12·1 (9·5–15·2)	$13·9 (10·8–17·6)
Percentage of total	10·7% (8·6–13·1)	6·2% (5·1–7·4)	10·2% (8·5–12·4)	18·0% (13·2–23·4)	10·0% (6·8–14·1)	8·7% (6·7–10·9)	13·5% (10·8–16·8)
Cirrhosis							
Total spending	$32·5 (27·0–40·4)	$1·2 (0·9–1·5)	$5·2 (4·1–6·5)	$16·9 (13·6–21·5)	$9·2 (7·6–11·4)	$16·8 (13·7–21·1)	$15·6 (12·9–19·5)
Attributable spending	$16·2 (13·3–20·7)	$0·0 (0·0–0·0)	$2·8 (2·2–3·5)	$9·4 (7·5–12·2)	$4·1 (3·3–5·1)	$7·5 (6·0–9·7)	$8·7 (7·0–11·1)
Percentage of total	49·9% (47·5–52·7)	1·3% (1·0–1·6)	53·4% (50·7–56·3)	55·2% (52·3–58·4)	44·4% (41·2–47·7)	44·4% (42·0–46·9)	55·8% (53·3–58·7)
Digestive diseases							
Total spending	$135·6 (127·9–144·3)	$10·6 (8·9–13·3)	$33·2 (30·8–35·6)	$49·0 (45·5–52·7)	$42·8 (39·4–47·1)	$77·7 (72·9–83·3)	$57·9 (54·1–62·7)
Attributable spending	$12·8 (9·7–15·9)	$0·0 (0·0–0·0)	$4·9 (3·7–6·1)	$5·0 (3·8–6·4)	$2·9 (2·1–3·7)	$8·1 (6·2–10·0)	$4·6 (3·3–6·1)
Percentage of total	9·4% (7·2–11·6)	0·2% (0·1–0·4)	14·7% (11·4–18·3)	10·2% (7·9–12·9)	6·7% (4·9–8·6)	10·5% (8·0–13·0)	8·0% (5·8–10·6)

Health-care spending is measured in billions of 2016 US dollars. Aggregated health conditions are ordered by attributable spending.

***Table:* Health-care spending attributed to risk factors by aggregated health condition category, 2016**

Risk factor attributions varied greatly across the four aggregated age groups (figure 2B). The majority of total attributable spending was at older ages, with 86·7% (95% UI 86·1–87·4) occurring in people aged 45 years and older. This is illustrated by the two risk factors with the highest attributable spending: for high BMI, 45·9% (43·0–49·1) of the total attributable spending was at ages 45–64 years and 42·3% (38·0–46·1) at ages

65 years and older, whereas for high systolic blood pressure, 37·7% (35·6–39·8) of attributable spending was at ages 45–64 years and 56·0% (53·6–58·3) at ages 65 years and older (figure 2B).

At ages 0–19 years, the largest attributable spending was related to child and maternal malnutrition ($4·1 billion, 95% UI 3·5–4·7) and high fasting plasma glucose ($2·7 billion, 1·9–4·5), although in terms of magnitude, the spending attributable to risk factors associated with this age group was very small (figure 2B). Moreover, this age group only made up 2·0% (95% UI 1·8–2·3) of total attributable spending, and only 5·1% (4·6–5·7) of health-care spending in this age group was attributable to modifiable risks.

Attributable spending for working age adults was considerably higher. For younger working-age adults (ages 20–44 years) the greatest spending was for high BMI ($27·4 billion, 95% UI 22·1–32·3) followed by alcohol use ($13·8 billion, 10·8–17·2), high fasting plasma glucose ($12·2 billion, 10·8–13·5), tobacco smoke ($11·6 billion, 9·9–13·5), and occupational risks ($11·1 billion, 9·8–12·4; figure 2B). This age group contributed 12·9% (95% UI 12·4–13·5) of all attributable spending, and had 16·8% (15·8–17·6) of health-care spending attributable to risk factors. For older working-age adults (ages 45–64 years), risk factors with the most attributable spending were high BMI ($109·0 billion, 85·1–128·1), high fasting plasma glucose ($69·2 billion, 63·3–75), high systolic blood pressure ($67·8 billion, 61·5–75·0), and dietary risks ($65·9 billion, 59·4–72·4). This age group contributed to 39·6% (38·6–40·6) of the attributable spending, and 32·0% (30·6–33·5) of the health-care spending in this age group was attributed to risk factors.

The oldest aggregated age category, which included spending on patients 65 years and older, had considerably greater spending attributable to modifiable risk factors. The greatest spending at these ages was for high BMI ($101·3 billion, 95% UI 69·5–132·7), high systolic blood pressure ($100·8 billion, 90·2–112·0), high fasting plasma glucose ($87·8 billion, 74·0–104·2), dietary risks ($66·8 billion, 59·8–73·9), and tobacco smoking ($58·4 billion, 51·7–65·4). Overall, 45·5% (95% UI 44·2–46·8) of attributable spending was on patients aged 65 years and older. For this age group, 34·9% (32·8–37·3) of health-care spending was attributed to risk factors.

Attributable health-care spending also varied by sex. Over all health conditions, females had $377·2 billion (95% UI 354·0–400·4) of attribute spending, whereas males had $353·2 billion (336·9–371·9). Females had more attributable spending than males for most aggregate health categories, including diabetes and urogenital, blood, and endocrine diseases; spending on risk factors; musculoskeletal disorders; and injuries; whereas males had more attributable spending on cardiovascular diseases (table). Despite females having more attributable spending, a larger fraction of health-care spending by males was attributable to modifiable risk factors. This was true for nearly all aggregate health categories (all except digestive disorders). This means that while females had more attributable spending than males in absolute terms, this can at least partially be explained by the fact that females generally have more health spending (due to longer life expectancy and, in many cases, higher health-care use). Of health-care spending for each sex, more could be attributed to modifiable risks for males.

Discussion

We estimated the fraction of US health-care spending in 2016 attributed to risk exposure. We estimated that 27·0% (95% UI 25·7–28·4) of personal health-care spending in 2016 captured by the Disease Expenditure Project was attributed to 84 modifiable risk factors in GBD 2017. Among adults (aged ≥20 years), five preventable risk factors—high BMI, high systolic blood pressure, high fasting plasma glucose, dietary risks, and tobacco smoke—accounted for a substantial proportion of attributable spending. The health conditions with the most attributable spending were cardiovascular diseases and diabetes. Attributable spending was heavily skewed toward older ages. Younger adults (ie, 20–44 years) accounted for a small portion of the total, although other research shows that it is at early ages when first exposure to many risks occur and when many patterns of healthy behaviours are formed.[20]

We found that the proportion of total health burden attributed to the modifiable risk factors considered in this study was substantially higher than the proportion of health-care spending attributed to those same risk factors—46·2% versus 27·0%. This discrepancy is due to two key factors. First, health-care spending is not perfectly associated with health burden, and for some health conditions, a large amount of spending occurs independent of health burden. This is especially true for pharmaceutical spending and health-care spending on prevention and disease management. Second, several of the health conditions that have the most attributable health burden actually have relatively little health-care spending. Examples with little total spending but a large fraction of the attributable health burden were lung cancer ($7 billion in total health-care spending), drug use disorders ($13 billion), and alcohol use disorders ($8 billion). Conversely, some health conditions with relatively large amounts of health-care spending have relatively small population attributable fractions, such as uncomplicated labour and delivery ($71 billion) and preventive dental care ($61 billion), which both have population attributable fractions of zero, and musculoskeletal disorders, which have over $380 billion in health-care spending but a population attributable fraction of only 22·3%. Ultimately, health-care spending and health burden are not well aligned, and many of the health conditions with the most spending are less attributable to the risks considered in this study.

Although the US population and health-care system is relatively distinct, this study can inform public health decisions in other countries. Globally, nearly 50% of health burden was attributable to modifiable risk factors in 2017.[14] While the USA spends more per person on health than any other country, the fact that a large portion of spending can be attributed to key risk factors is unlikely to be an anomaly. Lessons learned about which risk factors contribute the most to health-care spending and the methods employed in this study could be expanded to consider attributable spending in other countries.

To the best of our knowledge, this is the first study to produce comprehensive estimates of US health-care spending attributable to a large set of modifiable risk factors. Most previous studies on this topic have reported the attributable spending for a single health condition or a single risk factor.[21–28] These studies are not comparable to this study, or to each other, for two key reasons. First, studies use different definitions of attributable health-care spending (eg, many measure the spending on patients with a specific condition rather than measuring the spending attributable to that condition), and thus rely on different methodologies and data inputs. Second, studies generally do not account for the joint effects of multiple risk factors on a single medical condition or mitigating relationships between a risk factor, other risk factors, and comorbidities. A valuable contribution of our study is the broad perspective, including 154 mutually exhaustive health condition categories and 84 modifiable risk factors. This broad scope can provide crucial information for evaluating attribution of risk exposure and informing the design of public and private health promotion and prevention programmes. Of significant value to design of health promotion and prevention programmes is that attributable spending by condition is estimated considering the joint effects of all related risk factors.

A complicating factor when considering health promotion policy is the time lag between risk exposure and health-care spending. While attributable health-care spending is primarily at older ages, modifiable risks that lead to this spending might have existed much earlier in life. Thus, the beneficial effects of reducing risk factor exposure often occur in the decades that follow. This means that investment in health promotion and prevention programmes that seek to mitigate risk exposure, such as reducing obesity or tobacco use, might lead to health gains and potential spending reductions that for many individuals, particularly children and young adults, are decades in the future. Because risk exposure might have occurred earlier in life, this study highlights the importance of connecting health promotion policy at all stages of the life, and encourages better coordination across insurance programmes that often incentivise healthier living, as well as more investment in holistic, long-term risk reduction programmes.

There were six main limitations to this research. First, this study measures the attribution of health-care spending to modifiable risk factors. We use attribution in the epidemiological, relative sense, addressing the question of what proportion of an outcome (in this case, health-care spending) can be tied to risk exposure.[29] In this interpretation, attribution is measured at a single moment, such that reducing existing risk exposure might not necessarily lead to proportional reductions in attributable health-care spending in the long term. This is due to the complex relationships among health burden, life span, and health-care resource use, and is a limitation associated with nearly all attribution studies. Because average health-care spending per person and disease incidence tend to increase with age, improvements in health that lead to reductions in spending on one health condition might be replaced by spending on another. For these reasons, it would be a misinterpretation of these results to directly infer how spending would decrease based on reductions in risk exposure. Instead, this study highlights how much of the health-care spending that occurred in 2016 was attributable to these risk factors. Similarly, a challenge with all risk factor attribution studies, including the GBD estimates from which this present study draws input data, is attributing past exposure to current health burden and health-care spending. These challenges have been highlighted previously.[14,30] To the degree that the estimated population attributable fractions are underestimates of the true amount of attribution, our estimates of attributable spending will be a conservative lower bound.

Second, population attributable fractions directly linking risk factors and health-care spending do not exist. Instead, this study relied on population attributable fractions reflecting the relationship between risk factors and health outcomes, adjusted downwards to reflect how health-care spending is associated with health burden. Third, attributable spending estimates are based on reducing risk factors to their theoretical minimums, which in some cases is not a feasible public health goal. No estimates were made for partial reductions and it is unclear without further research how partial reductions in risk exposure might affect spending. Fourth, several modifiable risk factors were not included in this study, such as poor medication adherence, vaccine compliance, inadequate sleep, elevated stress levels, as well as more distal but crucially important drivers such as socioeconomic status. These excluded risk factors are likely to affect the incidence and prevalence of health conditions and might also affect health-care spending. While no list can ever be completely comprehensive, we believe that the 84 risk factors included in this study capture the vast majority of health-care spending attributable to policy-relevant modifiable risk factors. Fifth, as described above, the underlying input data used for this study are not measured with certainty, and estimates rely on necessary assumption. These assumptions are described elsewhere, although the uncertainty of these input data was propagated through our own calculation of uncertainty based on 1000 draws of underlying data. Sixth, despite illustrating a novel method and producing a unique comprehensive set of attributable spending estimates, these estimates are from 2016 and are 4 years out of date upon publication. These estimates cannot, as of now, be updated because the underlying health-care spending data by health condition, age, and sex are not available for any more recent years. Still, we believe these estimates remain of use as the relative magnitude across health-care spending categories and risk attribution are likely to evolve slowly.

In conclusion, spending attributable to 84 modifiable risk factors in the USA accounted for $730·4 billion (95% UI 694·6–768·5), which represented 27·0% (95% UI 25·7–28·4) of total US health-care spending in 2016. Among adults, five modifiable risk factors—high BMI, high systolic blood pressure, high fasting plasma glucose, dietary risks, and tobacco smoke—accounted for the most attributable spending, mainly through spending on cardiovascular disease; diabetes and urogenital, blood, and endocrine diseases; and management of metabolic risks. These estimates provide important information that can be used to more effectively design health promotion and prevention programmes.

Contributors

HJB and JLD completed the literature review. ALB, CC, and LL generated the figures and completed the data collection. JLD devised the study design. HJB, FM, and JLD wrote the first draft of the manuscript. AB, AC, and JLD managed the research. All authors contributed to the interpretation of the results and reviewed the final manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

Estimates produced in this study are publicly available on the Global Health Data Exchange.

For the **Global Health Data Exchange** see https://www.ghdx.org

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