You are kindly invited to attend the public defence of my PhD thesis entitled:

The obesity epidemic in Europe: Assessing the past and current mortality burden and the future of obesity

On Thursday 25th of April 2019 at 11:00 a.m. at the Academy Building of the University of Groningen, Broerstraat 5, Groningen.

A reception will follow.

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The obesity epidemic in Europe:
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Nikoletta Vidra
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Table of contents

Chapter 1: Introduction ........................................................................................................ 7

Chapter 2: Impact of different estimation methods on obesity-attributable mortality levels and trends: the Case of the Netherlands ................................................................. 41

Chapter 3: Past trends in obesity-attributable mortality in eight European countries: an application of age–period–cohort analysis ................................................................. 69

Chapter 4: Impact of obesity on life expectancy among different European countries, 1975-2012 .......................................................................................................................... 95

Chapter 5: Forecasting obesity in 18 European countries and the United States using the underlying epidemic wave pattern ................................................................. 121

Chapter 6: Discussion ................................................................................................... 151

English Summary ......................................................................................................... 179

Nederlandse samenvatting ......................................................................................... 183

Acknowledgements .................................................................................................... 188

About the author ......................................................................................................... 190
Introduction
Chapter 1

1.1. Problem statement

Obesity, defined as a Body Mass Index (BMI) of ≥30 kg/m² (WHO, 1998), has been increasing worldwide since the 1980s, to the point that it is now considered a global epidemic (Finucane et al., 2011). Europe has been hit hard by this epidemic, as it is currently the region with the second-highest obesity prevalence worldwide (in 2014, the average prevalence across the EU member states was 15.9%) (Eurostat, 2016), after the United States of America (US) (36.5% in 2011-2014) (OECD, 2014). There are, however, substantial variations in obesity prevalence levels between individual European countries (Eurostat, 2016).

Obesity is considered one of the biggest public health challenges of the 21st century (WHO, 2018a), not only because of its alarming prevalence rates, but its serious health effects. Compared to their non-obese counterparts, obese individuals are at higher risk of developing a range of diseases, including type II diabetes, several types of cancer, cardiovascular disease, (Guh et al., 2009), some of the so-called non-communicable diseases (NCDs) (WHO, 2018b). Obese people also face an elevated risk of all-cause mortality (Global BMI Mortality Collaboration, 2016).

As younger generations are exposed to environments that are becoming increasingly obesogenic (Reither et al., 2009), we can expect that the health burden of obesity will continue to rise, thereby posing considerable threats to the health of populations. Thus, there is an urgent need to estimate the health burden of obesity, especially at the population level, in order to acquire knowledge about the scale of the problem that can be used to guide public health policies.

Studies on the health burden of obesity at the population level generally consider both morbidity (disease burden) and mortality (death burden). As the effect of obesity on mortality is growing, this thesis will focus on mortality.

Earlier studies on the mortality burden of obesity were mainly seeking to describe the magnitude of the problem (e.g., (Allison et al., 1999; Flegal et al., 2005). The relatively few comparative studies on this topic have shown that in Europe, obesity's toll is especially worrisome. According to the Institute for Health Metrics (WHO, 2005; Institute for Health Metrics GBD 2016, 2018), which defines a BMI of 23 kg/m² as high (even though this definition contradicts the broadly used definition of normal weight range (18.5≥BMI≤24.9) (WHO, 1998),...
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Europe ranks first among global regions in terms of mortality attributed to high BMI. However, the Institute for Health Metrics provides estimates for a wide BMI range, and does not publish estimates that pertain solely to obesity (Institute for Health Metrics GBD 2016, 2018). The few available studies that have considered the role of obesity only, have demonstrated that the share of deaths that can be attributed to obesity (i.e., obesity-attributable mortality, or the fraction of deaths in a population that would be avoided if obesity were eliminated from that population) was 8% in the former EU-15 (Banegas et al., 2003); or, based on more recent findings, was 9% on average in Europe (Global BMI Mortality Collaboration, 2016).

While these previous studies on the mortality burden of obesity yielded valuable insights, they had a number of limitations. First, previous estimates of obesity-attributable mortality that were obtained by applying different methodologies cannot be readily used for comparative purposes (Flegal et al., 2015). Second, as most of these earlier studies focused on one specific point in time (i.e. Allison et al., 1999; Banegas et al., 2003; Flegal et al., 2004; Flegal et al., 2005), there is lack of knowledge about how obesity-attributable mortality has evolved over time. An exception is the Global Burden of Disease (GBD) study, which provided regular estimates of mortality at five-year time intervals from 1990 onwards, and has very recently started providing these estimates at one-year intervals (Institute for Health Metrics GBD 2016, 2018). Moreover, most studies that assessed the impact of obesity on life expectancy, which is another way to estimate obesity’s effect on mortality (Olshansky et al., 2005; Preston & Stokes, 2011), also focused on a unique point in time only. Third, most previous studies on obesity-attributable mortality focused on the US (i.e. Allison et al., 1999; Flegal et al., 2004), presumably because the epidemic is at a more advanced stage in the US, and because more data are available for that country. Thus, there is a lack of knowledge about this issue in Europe, where variations in obesity prevalence across countries could result in differences in obesity-attributable mortality. Fourth, most previous studies on obesity-attributable did not acknowledge that obesity and obesity-attributable mortality are complex phenomena that are affected not only by age and period (calendar year), but by birth cohort (group of individuals born in the same time period) (Reither et al., 2009; Diouf et al., 2010). Fifth, as obesity is an evolving epidemic, it is crucial that we forecast future obesity levels by taking into account the underlying wave pattern that is characteristic of an epidemic, which has not been done in previous research.
As it is apparent that Europeans are suffering from obesity, it is essential that we gain a deeper understanding of the associated mortality burden and the likely future progression of obesity in Europe. Given these gaps in the research, it is increasingly urgent that we provide past, and present estimates of obesity-attributable mortality and its effects on all-cause mortality and life expectancy, and future estimates of obesity for European countries. Moreover, by estimating obesity’s evolution and impact on mortality at the population level, we can gain a better understanding of the current and future magnitude of the problem and its effects on health services, which can be used to inform public policies. To explain and describe this impact, it is essential that we have information on the time trends in obesity-attributable mortality, and on the differences in these trends across countries and birth cohorts.

1.2. Objective, research questions, and novelties

The aim of this study is to provide new and detailed insights into how the burden of obesity affects mortality at the population level, and how obesity is likely to develop in the future in Europe. More specifically, this thesis assesses the evolution of obesity-attributable mortality over time and its impact on all-cause mortality across European countries, and uses the knowledge acquired through this investigation to predict future obesity.

The research questions that guided this study are:

1. What are the past levels of and trends in obesity-attributable mortality in Europe, both across calendar year and birth cohorts, and how do these levels and trends differ across European countries?

2. What are the effects of obesity on all-cause mortality levels and trends, and how do these effects differ between countries?

3. How is the obesity epidemic likely to evolve in the future?

This study encompasses several novelties. First, this study focuses on European countries. Whereas considerable research on this topic has been conducted in the US, the number of studies on obesity-attributable mortality and its effects on all-cause mortality levels in Europe is small. Second, it gives information about how these effects differ across European countries by applying a similar methodology to estimate obesity-attributable mortality. Third, in contrast to most previous studies, it examines time trends, rather than focusing on a single
point in time. Fourth, in light of the complexity of the obesity epidemic, it assesses age, period, and birth cohort effects, as well as patterns in past obesity and obesity-attributable mortality trends. Fifth, based on the obesity epidemic idea, this research uses the detailed knowledge acquired through this investigation of past trends and variation in these trends across countries to build a stronger foundation for estimating the future evolution of the obesity epidemic.

1.3. The obesity epidemic

Over the last three decades, levels of obesity, defined as a Body Mass Index (BMI) of ≥ 30 kg/m² (WHO, 1998), have increased dramatically. According to the nutrition transition theory, this trend was caused by considerable shifts in the structure and the overall composition of dietary and physical activity patterns, from a previous pattern of receding famine to a pattern dominated by nutrition-related NCDs. These changes, which include lower activity levels and increased consumption of processed and calorically dense foods, like fat and sugar, are associated with nutrition-related outcomes such as obesity (Popkin, 2006). These shifts reflect developments in economic conditions, income levels, demographic characteristics, and household production patterns (Popkin, 2006) that have contributed to an environment that promotes obesity; the so-called obesogenic environment (Swinburn et al., 1999). These shifts have not occurred simultaneously around the globe, as there are important contextual differences between countries (Popkin, 2006). Such developments, are however, currently the norm in Western societies (see 1.3.1 for more information on the contextual versus the individual determinants of the obesity epidemic).

The first indications that obesity was increasing were in the US and Europe at the end of the 1970s (Popkin et al., 2012). While researchers began describing obesity as a public health problem in the 1980s in the US and the UK, the issue was initially considered irrelevant elsewhere (James, 2008). It was not until 2000 that the World Health Organization recognised obesity as a global epidemic by publishing a report that called for acknowledging, preventing, and managing obesity (WHO, 1998).

The term epidemic is commonly used in the literature to describe obesity (WHO, 2000; Roth et al., 2004; i.e. Prentice, 2006), mainly because obesity has increased rapidly, reaching record-high levels. The development of an epidemic is best described by a wave pattern,
which an initial increase is followed by a plateau, and then a decrease. This framework has recently been applied to the obesity epidemic (Xu & Lam, 2018), but has not yet been thoroughly studied. The term epidemic will be used in this thesis despite its shortcomings, which include the current lack of a clear definition of the term, or a clear projection of when it might end (Lopez et al., 1994; Cliff & Haggett, 2006; Flegal, 2006; Xu & Lam, 2018).

As the younger generations are being exposed to environments that are even more obesogenic than those experienced by previous generations (Reither et al., 2009), we can expect that the obesity epidemic will continue to pose considerable threats to population health.

1.4. Obesity prevalence in Europe, levels and trends

According to 2016 estimates, 13% of the world’s adult population (11% of men and 15% of women), or over 650 million individuals, were obese (WHO, 2017). The US is the country with the highest prevalence: in 2014, an estimated 36.5% (34.3% of men and 38.3% of women) of Americans were obese (OECD, 2014; Ogden et al., 2017). In a comparison of obesity levels between regions of the globe, Europe ranks second after the US, with an estimated average prevalence of 15.9% across the EU member states. In Europe, men and women have nearly the same obesity levels: in 2014, 16.1% of men and 15.7% of women were classified as obese (Eurostat, 2016).

The obesity epidemic in Europe is, however, far from uniform, as the obesity level is almost three times as high in some countries as in others (Eurostat, 2016). The lowest obesity levels have been reported in Italy (10.7%) and the Netherlands (13.3%), and the highest obesity levels have been reported in the UK (26.2%) and Malta (26.0%) (Eurostat, 2016; Baker, 2018). Broken down by region, it appears that Central, Eastern, and Southern Europe have higher obesity prevalence rates than Western and Northern Europe.

These large differences in obesity prevalence levels across Europe can be at least partly explained by differences in individual and contextual factors, such as socioeconomic conditions and lifestyle and nutritional factors (Berghofer et al., 2008). Specifically, there are substantial socioeconomic disparities across Europe (Hruby & Hu, 2015) that affect the obesity risk. People with lower socioeconomic status tend to be at greater risk of becoming obese (Monteiro et al., 2004; Hruby & Hu, 2015), possibly because they have limited access to health
care and education, insufficient income to purchase healthy foods, and limited access to opportunities to engage in physical activity (Malik et al., 2013). Yet such associations are not straightforward at the population level: for reasons that are not clear, wealthier countries may report having obesity levels that are similar to those of poorer countries (Blundell et al., 2017). Nutritional factors seem to explain some of these differences. European countries vary considerably in terms of their food availability, cultural values, local food habits and traditional foods, and alcohol consumption levels (Blundell et al., 2017). For instance, Southern European countries seem to be abandoning the traditional Mediterranean diet, which is inversely associated with obesity risk (Panagiotakos et al., 2006; Kontogianni et al., 2008), and to be moving towards adopting less ‘healthy’ dietary patterns. Food availability also varies between countries. For example, fruits and vegetables are much more widely available in Southern Europe than in the CEE (Pomerleau et al., 2003); whereas until recently, the supply of dairy products was greater in Western and Northern Europe than in other regions (Birt et al., 2017). Meanwhile, physical activity levels are much lower in Southern and Central Eastern European countries than in Western and Northern European countries (Martinez-Gonzalez et al., 2001). These factors help to explain the differences in obesity prevalence between the European regions, but more research is needed to fully disentangle them (Blundell et al., 2017).

When examining obesity prevalence trends, several crucial pieces of information and patterns emerge. The worldwide prevalence of obesity nearly tripled between 1975 and 2016 (WHO, 2017). In the US, the magnitude of the increase in obesity was even greater between 1980 and 2008, which resulted in the US having the highest levels of obesity in the world (Finucane et al., 2011; Global BMI Mortality Collaboration, 2016). For example, among US adults aged 20–74, the age-standardized obesity prevalence increased from 15.0% in 1976-80 to 34.3% in 2007-2008 (NHANES) (Ogden & Carroll, 2010). While precise, reliable data on obesity prevalence for Europe is missing for this period, it is clear that obesity has been increasing in Europe since the 1980s – albeit at a slower pace than in the US, and with differences across the regions (Finucane et al., 2011; NCD Risk Factor Collaboration, 2016). In some European countries, a threefold increase in obesity prevalence between 1990 and 2010 has been reported (WHO, 2009; WHO, 2018a).
When BMI trends are considered, we see that for men, the average BMI has been increasing a bit more rapidly in Western and Central Europe than in Eastern Europe (0.6, 0.4, and 0.2 kg/m² per decade, respectively), and rose at a pace of 1.1 units from 1980 to 2008 in the US (Finucane et al., 2011). For women, BMI increased 0.4 units per decade in Western Europe, remained relatively stable (0.2 kg.m² per decade) in Central and Eastern Europe (CEE), and increased 1.2 kg/m² in the US (Finucane et al., 2011).

Why the obesity epidemic began earlier and progressed more rapidly in the US than in Europe is a research question that deserves attention. A number of hypotheses have been proposed to explain these international differences, including one that cites a change in the US agricultural and food policy tool (farm bills) in the 1970s that facilitated the production of low-cost products, such as corn and soybeans, which were used to produce additives, such as corn syrup and hydrogenated vegetable oils (Alston et al., 2006; Schoonover & Muller, 2006). This shift in turn resulted in considerable changes in the food supply, such as greatly increased food production, which led to bigger food portions; the extensive use of sweetening agents; and the greater availability of affordable, energy-dense food (Rodgers et al., 2018). However, as was already mentioned, nutritional factors related to food availability, cultural values, local food habits and traditional foods that differ between the US and Europe also contributed to the observed variation.

Europe adopted similar changes in food production at a later stage, and at lower levels. Among the reasons for this delayed response are that Europe has stricter agricultural policies than the US (Cutler et al., 2003). Moreover, European countries differ from the US in terms of their socioeconomic conditions, food policies, access to food technology (Cutler et al., 2003), cultural values, local food habits, and traditional foods (Blundell et al., 2017). Such differences exist not only between the US and Europe, but across European countries.

1.5. The burden of obesity at the individual level

Obesity constitutes a major health burden, and negatively affects almost every aspect of a person’s health. Obesity increases the risk of developing various comorbidities, and adversely affects quality of life. Obesity also has a marked impact on life expectancy, as it shortens the average life span and increases the risk of premature mortality (Fontaine et al., 2010).
Thus, the effects of obesity on health are long-lasting. Being obese is associated with an increased risk of developing a plethora of diseases, including type II diabetes, several types of cancer (e.g., cancers of the breast, colon and rectum, endometrium, oesophagus, kidney, ovary, and pancreas), cardiovascular disease, stroke, hypertension, hypercholesterolemia, hypertriglyceridemia, arthritis, and asthma (Guh et al., 2009; Harvard School of Public Health, 2018a). Most of these diseases belong to the spectrum of the so-called non-communicable diseases (WHO, 2018c).

Obesity affects a person’s health through various pathways, ranging from the mechanical stress caused by having extra body weight, to much more complex mechanisms involving inflammatory processes (Harvard School of Public Health, 2018b). Specifically, obesity causes a state of chronic low-grade inflammation that is induced by a variety of hormones produced by the adipose tissue. This inflammation plays a central role in the development of obesity-related health complications (Greenberg & Obin, 2006). The epidemiological evidence indicates that the relationship between BMI and mortality follows a J- or a U-shaped curve, with increased mortality at both lower and higher BMI levels (i.e. Calle et al., 1999; Seidell et al., 1999; Katzmarzyk & Ardern, 2004; Global BMI Mortality Collaboration, 2016). It is therefore clear that people who are obese have significantly higher all-cause mortality risks that normal-weight individuals (broadly BMI between 20-25 kg/m²), and the more obese a person is, the higher his or her relative risk (RR) of mortality is (Global BMI Mortality Collaboration, 2016).

Recently estimated RRs range from 1.27-1.64 (Lobstein & Leach, 2010; Flegal et al., 2013; Global BMI Mortality Collaboration, 2016), and show that an obese individual has a risk of dying that is 27% to 64% higher than that of a normal-weight person. Thus, the epidemiological evidence suggests that obesity has a considerable impact on mortality. The effect on mortality of being obese is greater than the effect of being overweight (broadly defined as a BMI between 25 and 30 kg/m²) (Ärnlöv et al., 2011; Carlsson et al., 2011), and increases as the severity of obesity increases, according to RR estimates by obesity severity (Global BMI Mortality Collaboration, 2016).

Studies that have looked at the years of life lost (YLL) associated with obesity showed that there is an association between excess weight and YLL, which increase as obesity increases.
This association differs depending on a person’s age, sex, race, and smoking history. For instance, Fontaine estimated that at age 50, obese white men can expect to lose four years of life; obese white women and black men will lose three years of life; while obese black women will experience no reduction in years of life (Fontaine et al., 2003). Finkelstein et al. (2010) estimated that at age 18, individuals with a BMI>40 have projected YLL ranging from five (black female never smokers) to 12 years (white male current smokers).

1.6. The mortality burden of obesity at the population level

Obesity has severe effects on health at the individual level, which, when accumulated, pose a threat to the health of populations. Given the general upward trend in obesity and its consequences, especially among the younger generations, the estimation of obesity’s burden at the population level seems especially important. The health burden of obesity at the population level can be viewed in terms of morbidity (disease and disability burden) and mortality (mortality burden). Obesity’s effect on morbidity has been extensively studied, and the research on this issue in Europe has yielded important knowledge. One way of looking at this effect is through the use of Disability-Adjusted Life Years (DALYs), which the WHO has defined as “the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability” (WHO, 2018d). In 2010, overweight and obesity were estimated to cause 3.8% of DALYs globally (Ng et al., 2014) and 10% of DALYs in Western and Central European countries (Loring & Robertson, 2014).

Another way of looking at the impact of obesity on morbidity is by examining the importance of non-communicable diseases (NCDs), like cardiovascular diseases (such as myocardial infarction and stroke), cancers, diabetes, and chronic respiratory diseases (such as chronic obstructive pulmonary disease and asthma) (WHO, 2018c). Although all regions across the globe are suffering from the disease burden of obesity, Europe has been the most affected in terms of NCDs. According to the WHO, 85% of the disease burden and 75% of all deaths in the European region are due to NCDs. Obesity increases the risk associated with most of these NCDs (WHO, 2005; WHO, 2018b). It is therefore clear that obesity has a considerable impact on morbidity, especially in Europe. With the progression of the obesity epidemic, the health effects of obesity are increasingly resulting in mortality effects. Thus, as the obesity epidemic
advances, studying the mortality burden at the population level becomes increasingly important.

This section gives an overview of earlier studies on the mortality burden of obesity, and distinguishes between two ways of assessing the mortality burden of obesity: namely, obesity-attributable mortality (1.6.1) and the impact of obesity on all-cause mortality (1.6.3). It also takes into account the age-period-cohort dimension of obesity (1.6.2), and looks at the small number of earlier studies that estimated the future trajectory of the obesity epidemic (1.6.4).

1.6.1. Obesity-attributable mortality

The effect of obesity on mortality at the population level is usually estimated with obesity-attributable mortality, either by assessing the obesity-attributable mortality fraction (the share of deaths in a population that would be avoided if obesity were eliminated from that population), or by estimating the obesity-attributable deaths (the share multiplied by all deaths in the population) (Mehta & Chang, 2012).

There are several existing methodologies for estimating obesity-attributable mortality, each of which has different data demands. Most commonly, however, the prevalence of obesity among the studied population and the relative risk (RR) of mortality associated with obesity are the key inputs in such analyses (Flegal et al., 2004; Flegal et al., 2013).

Previous studies on this topic mainly focused on the US and provided divergent estimates, probably due to the use of different methodologies and data (Flegal et al., 2015). The previous studies conducted in the US estimated that the obesity-attributable mortality fraction ranged from 3% to 15% (Global BMI Mortality Collaboration, 2016). Due to differences in the methodologies, data, and time periods used in these studies, the resulting estimates cannot be readily compared (Flegal et al., 2015).

As was previously noted, the existing research on this topic for Europe is limited (Banegas et al., 2003; Danaei et al., 2009; Konnopka et al., 2011; Global BMI Mortality Collaboration, 2016). The few such studies that have been conducted estimated that the mortality fractions attributable to obesity are, on average, 8% in the EU-15, or 9% in the European region (Banegas et al., 2003). However, as these studies used different methodologies and examined different years and different countries, the results of these studies are not comparable.
There is also limited research evidence on how obesity-attributable mortality evolved over time. One of the few existing studies on this issue, Katzmarzyk & Ardern (2004), estimated the share of deaths attributable to overweight and obesity in Canada from 1985 to 2000, and found that this share increased over time, from 5.1% to 9.3% (Katzmarzyk & Ardern, 2004). The Global Burden of Disease study estimated that mortality due to high BMI (BMI ≥ 23kg/m²) (i.e., not solely to obesity) increased from 1990 (8.7%) to 2005 (12.83%), and then stagnated through 2017, the most recent year estimated (12.84%) (Institute for Health Metrics GBD 2016, 2018).

Obesity-attributable mortality is an important measure of a population’s health. While estimating it is challenging, the levels and time trends of obesity-attributable mortality can provide a more detailed perspective on the burden of obesity at the population level, as well as important knowledge about the dimensions of the problem that can be used to guide public health initiatives.

### 1.6.2. The age, period, and cohort dimensions of obesity

In studying the time trends in obesity-attributable mortality, it is important to keep in mind that obesity is a complex phenomenon with three different dimensions: age, period, and cohort. (Reither et al., 2009). Age, period, and cohort effects all refer to some type of associated time variation, each of which has its own significance (Reither et al., 2009).

Age effects represent the distinctive biological and social processes related to the different life course stages of individuals (Reither et al., 2009). A person’s age significantly affects the implications of being obese, as both physiological and social changes are associated with aging, such as declining levels of physical activity (Reither et al., 2009).

Period effects are observable when individuals are affected by changes over time periods or calendar years that influence all age groups simultaneously, such as shifts in cultural, social, economic, and physical environments (Reither et al., 2009). In the obesity context, period effects are, for example, associated with technological innovations in food preparation, the move to less strenuous work, the increased availability and affordability of calorically dense foods due to changes in US agricultural policy (Reither et al., 2009).
Birth cohort refers to a group of individuals who share an initial event, like birth or marriage, in the same time period. These individuals move through life together from in utero to critical stages of the life course. In this context, birth cohort membership can indicate the degree to which individuals are receptive to societal and social changes. It can also reflect individuals’ early life exposures, which can have long-lasting consequences (Bijlsma et al., 2012), especially in the obesity context. For example, the younger birth cohorts of today have spent most of their lives in obesogenic environments. As a result, they are more likely than members of older generations to adopt a calorically-rich diet and a sedentary lifestyle, which predisposes them to gain weight – and thus to become obese – either early or later in life (Reither et al., 2009). This weight gain may be expected to have long-lasting health consequences.

There are a few previous studies that examined the age, period, and cohort effects on obesity prevalence in the US, France, Ireland, Korea, and Australia (Allman-Farinelli et al., 2008; Kwon et al., 2008; Reither et al., 2009; Diouf et al., 2010; Xu & Lam, 2018). These studies provided significant evidence that all three dimensions are significant. As all three dimensions affect obesity, they might also affect obesity-attributable mortality. Thus far, however, no studies have addressed this question directly.

Yu investigated the age patterns of mortality differentials across cohorts born between 1901 and 1957, and found that mortality attributable to overweight and obesity was increasing in the most recent cohorts in the US (Yu, 2012). Masters examined obesity-attributable mortality by birth cohort, and found more deaths among younger than older birth cohorts in the US (Masters et al., 2013).

Thus, there are large gaps in our knowledge of the age, period, and cohort effects on obesity-attributable mortality, particularly in Europe. Disentangling the distinctive effects of age, period, and cohort is especially important for understanding how obesity and obesity-attributable mortality developed, determining which factors contributed to this increase, and enabling us to predict the future.

1.6.3. Impact of obesity on all-cause mortality/life expectancy

Another way of assessing obesity’s mortality burden is by estimating the potential impact on all-cause mortality or life expectancy. As obesity has been increasing in recent decades, there has been widespread concern about this potential impact (Leon, 2011; Walls et al., 2012).
Very few studies have assessed the impact of obesity on life expectancy, except for the work of Olshansky et al. and Preston et al., which found that obesity has a life-shortening effect (Olshansky et al., 2005; Preston & Stokes, 2011). Both of these studies used as an indicator the potential gain in life expectancy (PGLE), defined as “the added years of life expectancy for the population if the deaths from a particular cause were removed or eliminated as a competing risk of death” (Lai & Hardy, 1999). Olshansky et al. (2005) estimated the potential gain in life expectancy (PGLE) due to obesity for the United States in 2000, and found that if obesity were eliminated, life expectancy at birth would be higher, ranging from 0.21 to 1.08 years, depending on gender and ethnicity. Preston et al. (2011) estimated the extent of international variation in life expectancy at age 50 attributable to differences in obesity for 16 countries in 2006. Their study sample was made up primarily of European countries, as well as the US. They found that the largest impact of obesity was in the US, where life expectancy at age 50 was reduced by 1.54 years for women and by 1.85 years for men. The results further showed that in the European countries studied, obesity led to a loss in life expectancy that ranged from 0.50 years in Switzerland to 1.19 years in Sweden for men, and from 0.72 years in Sweden to 1.37 years in Poland for men.

Both of these studies looked at the effect of obesity on life expectancy at one point in time only. Given that the impact of obesity on life expectancy appears to be especially large in the US, but is still considerable in European countries (Preston & Stokes, 2011), the question of whether obesity has already affected life expectancy trends has been raised (Alley et al., 2011). This issue has been debated among researchers, with some scholars suggesting that it may be a small contributor to differences in life expectancy trends, but that it is unlikely to fully account for them (Alley et al., 2011). Other scholars have argued that the adverse impact of obesity has been overshadowed by other factors that have led to improvements in life expectancy, such as the decline in smoking and improvements in the treatment of cardiovascular diseases and other obesity-related comorbidities (Leon, 2011; Preston & Stokes, 2011; Walls et al., 2012). Some authors have asserted that life expectancy gains would have been greater without the effect of obesity (Preston & Stokes, 2011), and that the decelerating trends in the rate of improvement in mortality in the US in particular are a direct consequence of obesity’s impact (Preston et al., 2018).
In this context, having more information about the current and past impact of obesity on life expectancy, especially in Europe, will provide meaningful insights into the overall impact of obesity.

1.6.4. The future burden of obesity

In recent decades, obesity has increased dramatically across the globe. As this trend raises serious public health concerns, it is very important that we estimate future obesity developments, which could turn out to be even more distressing than current trends.

As the health effects of obesity can be long-lasting, it is possible that the newer birth cohorts, will face elevated health risks in the future. As younger cohorts are increasingly exposed to obesogenic environments, they are predisposed to developing obesity earlier in life (Reither et al., 2009). Thus, they may be obese for longer than previous generations, and could therefore experience more severe effects related to obesity as they grow older.

To estimate future levels of obesity, it is important to assess whether and, if so, when the obesity epidemic will reach a plateau, and then turn from an increasing to a declining trend. At present, there is some evidence that the increasing trend has levelled off. There is also some more contested evidence that a plateau has been reached, and that obesity prevalence has started to decrease, especially in children (Salanave et al., 2009; Sharma et al., 2009; Olds et al., 2010; Rokholm et al., 2010; Ogden et al., 2012; Visscher et al., 2015).

For example, several recent studies have reported a stagnation or a levelling off of obesity levels in some countries, like the US (Rokholm et al., 2010), Russia, former Yugoslavia, the Czech Republic, and Lithuania (Silventoinen et al., 2004). In addition, the stabilization of obesity trends has been observed in specific sub-populations, such as in adults with high socioeconomic status in regions within Switzerland, France, and Finland (Visscher et al., 2015); while a decrease in obesity has been reported in children only (Ogden et al., 2014; Visscher et al., 2015), to the best of our knowledge.

The interpretation of these stagnating trends is not straightforward, and has been a matter of controversy in the literature. Some researchers have suggested that obesity levels have reached a plateau, while others have argued that bias may have led to the misinterpretation of the data, or that this stagnation is only temporary, and will likely be followed by further
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Previous studies that focused on projecting future obesity prevalence trends have used different methodologies and reached different conclusions (i.e. Finkelstein et al., 2012). Some of these studies applied linear forecasts based on the assumption that obesity will continue to increase at its current rates (Wang et al., 2008); while others took into account the recent evidence indicating that obesity prevalence may be levelling off, and projected that a plateau will soon be reached (Schneider et al., 2010; Finkelstein et al., 2012; Thomas et al., 2014). Most of these studies focused their attention on the US, and failed to take into account the epidemic character of obesity, which implies that the increasing trend will eventually turn into a decline (Xu & Lam, 2018).

Thus, there is a clear need for additional knowledge that can be used to project the future evolution of the obesity epidemic. Based on the detailed knowledge acquired through the investigation of past trends and variation in these trends across countries, this research is helping to build a stronger foundation for estimating the future evolution of the obesity epidemic.

1.7. Approach

This thesis takes a multidisciplinary approach, combining knowledge, methods, and data from both demography and epidemiology. It focuses on the mortality burden of obesity at the population level in Europe by using cross-country comparisons and taking a temporal approach.

More specifically, both demographic population-level mortality data and epidemiological survey data are used to estimate obesity-attributable mortality. Epidemiological methods, such as methods for estimating obesity-attributable mortality, are used in combination with demographic methods, such as age-period-cohort analysis, life table techniques, and the (Lee-Carter) forecasting methodology.
By studying the mortality burden of obesity at the population level in Europe, important knowledge that has so far been lacking or only very broadly available can be obtained, and can be used to discern the problem’s true dimensions.

A cross-country comparison is considered essential for describing and highlighting the existing variations in obesity and in the mortality burden of obesity, as this approach provides insights into the differential timing and intensity of the epidemic, and can thus deepen our understanding of the general nature of the epidemic.

This thesis also takes a temporal approach, which has been largely lacking up to now. Specifically, the thesis focuses on describing the long-term annual time trends in obesity-attributable mortality and its effects on all-cause mortality, thereby providing a detailed view of the past and the present. In addition, by including the birth cohort dimension, this thesis aims to account for the complexity of the obesity epidemic. Moreover, this thesis provides estimates of the future evolution of the obesity epidemic. In formulating these estimates, the detailed descriptions of the past trends and the existing differences across countries, as well as of the underlying wave pattern of obesity epidemic, provide a strong foundation.

### 1.8. Data and methods

In this thesis, a variety of data and methods from both demography and epidemiology are used. These epidemiological data are mainly obesity prevalence data and the RRs of dying from obesity. These data are needed to estimate the share of mortality due to obesity.

Two types of obesity prevalence data are used. First, national health survey data, such as the data from the Dutch Interview Health survey, are employed (Centraal Bureau voor de Statistiek, 2018). Second, population-level obesity estimates are used. These estimates are based on national health survey data when available, but also include estimated data from the Global Burden of Disease study (GBD) and from the more recent Non-Communicable Disease (NCD) Risk Factor Collaboration study, as they provide comparable estimates for a large number of countries and for a long period of time (Ng et al., 2014; Global BMI Mortality Collaboration et al., 2016; Abarca-Gómez et al., 2017; Centraal Bureau voor de Statistiek, 2018).
The relative risks of mortality associated with obesity, which are essential for estimating obesity-attributable mortality, are derived from different meta-analyses and literature reviews. The meta-analysis by Flegal (2013) provides information on sex-specific worldwide and European RRs, while the meta-analysis by Wang (2015) provides information on age-sex specific worldwide RRs. Furthermore, a review of studies mainly from Western Europe and the US by the DYNAMO project provides information on age-and sex-specific RRs (Lobstein & Leach, 2010). RRs for specific causes of death are also used (Danaei et al., 2009; GBD 2013 Risk Factors Collaborators, 2015) to estimate cause-specific mortality as an intermediate step in estimating all-cause mortality attributed to obesity.

The demographic data used in this thesis include all-cause and cause-specific mortality data and the related population numbers. The all-cause mortality and exposure population numbers are obtained from the Human Mortality Database (Human Mortality Database, 2018), while the cause-specific mortality data are retrieved from the WHO Mortality Database (WHO, 2016). These data are essential for estimating obesity-attributable mortality deaths and rates and the impact of obesity-attributable mortality on overall mortality.

We employ both demographic and epidemiological methods. To estimate obesity-attributable mortality, we evaluate and use various epidemiological methods that fall into two broad categories: those that use all-cause mortality data (all-cause approaches) and those that use cause-specific mortality data (cause-of-death approaches), which differ from the all-cause data in that they estimate the deaths from each cause of death attributed to high BMI, and not solely obesity, and then sum these up. We also develop a cause-specific method to capture the effect of obesity only.

Advanced demographic methods are also employed in this thesis. An age-period-cohort (APC) analysis is undertaken to disentangle and assess the distinctive effects and patterns of age, period, and birth cohort effects in past obesity-attributable mortality trends. Life table techniques are used to estimate life expectancy at birth and the impact of obesity on life expectancy by estimating life expectancy if obesity-attributable mortality were eliminated. A novel approach for forecasting obesity prevalence that takes into account the wave pattern of the obesity epidemic was implemented in the well-known Lee-Carter mortality projection
demographic technique, and applied to the logit of the obesity prevalence in order to obtain estimates of the future evolution of obesity.

Whenever needed, the smoothing of data and the age standardization of the measures of interest are also applied.

1.9. Thesis outline

In Chapter 2 of this thesis, the various methods available for estimating obesity-attributable mortality are applied, compared, and assessed in terms of their impact on the levels of and the trends in obesity-attributable mortality, but also in terms of their advantages and limitations. A method that uses a cause–specific approach and captures mortality attributable to high BMI (≥23Kg/m²) is also adapted and developed to capture obesity-attributable mortality. This chapter focuses on the Netherlands as a case study, but answers the general question of which methods can be applied in a European setting when taking a temporal approach.

The second part of the thesis, Chapters 3 to 5, deals with answering the three subsequent research questions, as listed in 1.2.

In Chapter 3, the first research question is addressed by studying the long-term past trends of obesity-attributable mortality in eight European countries: namely, the Czech Republic, Germany, Finland, France, Hungary, Italy, Poland, and the United Kingdom (UK). Furthermore, an age-period-cohort analysis is applied to describe the impact and the birth cohort patterns in the trends in obesity-attributable in the studied countries.

The second research question is addressed in Chapter 4, in which the impact of obesity on all-cause mortality – and, consequently, on life expectancy – is assessed by taking a cross-country, temporal approach. Specifically, obesity-attributable mortality is estimated, and then the potential gain in life expectancy if mortality due to obesity were eliminated is assessed along with the differences between levels, trends, and countries. This study focuses on 26 European countries in the 1975-2012 period, and uses the US as a comparative country.

Chapter 5 addresses the third research question by forecasting obesity, while taking into account the epidemic wave pattern of obesity, using a novel projection methodology. By modifying the Lee-Carter projection methodology so that it can capture the future evolution
of obesity as an epidemic (which implies that a maximum level will be reached, and followed by a decline), important knowledge will be gained about the stages of the epidemic in the countries studied, and about the timing and the future evolution of these stages. This study focused on 18 European countries and the US.

In the final part of this thesis, Chapter 6, the main results are summarized and discussed in detail. In addition, the implications of the findings for public health policies, as well as for future research questions, are presented.
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Impact of different estimation methods on obesity-attributable mortality levels and trends: the case of the Netherlands

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Abstract:

The available methodologies to estimate the obesity-attributable mortality fraction (OAMF) affect the levels found, and hamper the construction of time series. Our aim was to assess the impact of using different techniques to estimate the levels and the trends in obesity-attributable mortality for the Netherlands, 1981-2013. Using Body Mass Index (BMI), all-cause and cause-specific mortality data, worldwide and European relative risk (RR), we estimated OAMFs using three all-cause approaches (partially adjusted, weighted sum, and the two combined) and one cause-of-death approach (Comparative Risk Assessment; CRA). We adjusted the CRA approach to purely capture obesity (BMI≥30 kg/m²). The different approaches led to a range of estimates. The weighted sum method using worldwide RRs generated the lowest (0.9%), while the adjusted CRA approach using 2013 RRs generated the highest estimate (1.5%). Using European-specific RRs instead of worldwide RRs resulted in higher estimates. Most of the approaches revealed an increasing OAMF over the period 1981-2013, especially from 1993 onwards, except for the adjusted CRA approach, among women. Estimates of OAMFs levels and trends differed depending on the method applied. Given the limited available data, we recommend using the weighted-sum method to compare obesity-attributable mortality across European countries and over time.

Keywords: obesity, mortality, the Netherlands, estimation, CRA approach, partially adjusted method, weighted sum method, population-attributable fraction
2.1. Introduction

Over the past three decades, the prevalence of obesity has risen tremendously across the globe (Finucane et al., 2011), to the point that it is now considered a pandemic (WHO, 2000; Finucane et al., 2011). Obesity constitutes a major health burden (Wang et al., 2011), as there is evidence of strong links between obesity and life-threatening chronic diseases, such as type II diabetes, cardiovascular disease, stroke, and multiple types of cancer (Field et al., 2001; Berrington de Gonzalez et al., 2003; Calle & Kaaks, 2004). As a consequence, the rise in obesity has led to recent declines in survival and life expectancy (Calle et al., 1999). Because the health burden associated with obesity is so significant, its estimation bears high relevance and importance.

In quantifying the health burden of obesity at the population level, the population attributable fraction (PAF) is commonly used (WHO, 2000). The PAF is defined as the proportion of total events (e.g. deaths) in a population that could be prevented if a particular risk factor (e.g. obesity) could be eliminated (WHO, 2000). The PAF combines information on the proportion of the population exposed to obesity (prevalence) with the relative risk (RR) of dying from obesity (Laaksonen et al., 2010).

Over the years, many methodologies for estimating obesity-attributable mortality fractions (OAMF) by means of different PAF formulas have been developed, ranging from approaches that use RRs for all-cause mortality (all-cause approach), to more recent approaches that use RRs for obesity-related causes of death (cause-of-death approach) (See Supplementary Material 1). Within the all-cause approach, there are various methods for estimating OAMF that require varying degrees of data availability (see the Supplementary Material 1). Thus, implementing some of these methods can be difficult. The partially adjusted method (Allison et al., 1999; Banegas et al., 2003; Mokdad et al., 2004; Borch et al., 2011), which multiplies the adjusted RR of dying from obesity with the obesity prevalence in the studied population, is often used (Rockhill et al., 1998; Flegal et al., 2004). In the weighted sum method, unadjusted RRs by age and sex (for instance) are commonly weighted by the obesity prevalence within each subgroup (Benichou, 2001). The Comparative Risk Assessment (CRA) methodology, which was recently developed by the Global Burden of Disease (GBD) Study, uses cause-specific mortality, cause-specific RRs, and the population distribution of BMI to
estimate cause-specific shares of mortality due to high BMI (≥23 kg/m²) (Ezzati et al., 2004). Because of their focus on high BMI, the CRA estimates cannot be readily compared with other estimates that focus strictly on obesity (BMI≥30 kg/m²).

As previously published research has shown, estimates of obesity-attributable mortality vary depending on which methodology is used (Flegal et al., 2015). For example, in 1991 the number of obesity-related deaths in the United States in 1991 was ~196,000 when the weighted sum method was used, and was ~230,000 obesity-related deaths when the partially adjusted method was applied (Flegal et al., 2004).

The use of different methods, and the range of outcomes these methods generate, not only cause uncertainty about the true population-level effects of obesity on mortality in a single calendar year, but also hamper the construction of time series. First, the use of different methods over time makes it difficult to construct time series of PAFs based on existing studies. Second, data limitations can also pose challenges when estimating time series. In particular, more advanced PAF methods require data that simply are not consistently available over a longer time period (see Supplementary Material 1). To date, only one previous study has examined the long-term trends in obesity-attributable mortality, and did so for Canada using an all-cause approach (Katzmarzyk & Ardern, 2004). In addition, the GBD study estimates mortality due to high BMI, every five years from 1990 to 2015 (GBD 2015 Risk Factors Collaborators, 2016). But because the GBD study is updated regularly based on the latest research findings, it is unclear whether the same methodology was applied and the same cause-of-death and RR data were used in each update (GBD 2013 Risk Factors Collaborators, 2015; GBD 2015 Risk Factors Collaborators, 2016).

Previous research on obesity-attributable mortality has focused on the United States (Allison et al., 1999; Flegal et al., 2004; Mokdad et al., 2004), in part because of the availability of large cohort studies for the US as a whole. For Europe, by contrast, there is little available information on obesity-attributable mortality levels, and even less information on trends. To the best of our knowledge, the influence of the chosen method on estimates of obesity-attributable mortality trends has not previously been assessed.

Our objective is to assess the impact of the use of different estimation techniques on both the levels of and the trends in obesity-attributable mortality. More specifically, we compare
Impact of different estimation methods on obesity-attributable mortality

2.2. Materials and Methods

2.2.1. Methods for calculating obesity-attributable mortality

Below we present the different PAF formulas that we will use to estimate the obesity-attributable mortality fraction (OAMF).

Selected all-cause approaches

We follow the terminology, namely partially adjusted and weighted sum method as described by Flegal et al. (2004). The partially adjusted method and the weighted sum method (Benichou, 2001; Flegal et al., 2004) are both all-cause approaches (see Supplementary Material 1) that use the same PAF equation:

$$\text{PAF} = \frac{P \cdot (RR - 1)}{1 + P \cdot (RR - 1)} \quad (\text{Equation 1})$$

where $P$ is the proportion of the population exposed to obesity, and $RR$ is the (unadjusted) relative risk of mortality associated with obesity (Rockhill et al., 1998). The partially adjusted method combines one overall adjusted RR of dying from obesity with the observed overall obesity prevalence. The weighted sum method uses unadjusted subgroup-specific RRs and subgroup-specific prevalence.

In fact, the weighted sum method commonly uses a modified version of equation 1, which distinguishes multiple categories of the exposure variable, such as different age groups:

$$\text{PAF} = \frac{\sum P_i \cdot (RR_i - 1)}{1 + \sum P_i \cdot (RR_i - 1)} \quad (\text{Equation 2})$$

where $i$ refers to the $i$th exposure category.

In addition to the above-mentioned approaches, we also used a combined all-cause approach in which we used age- and sex-specific obesity prevalence and age-adjusted and sex-specific RRs in equation 2. A single PAF value is achieved through weighting by sex.
Comparative Risk Assessment (CRA) approach

The Comparative Risk Assessment Approach (CRA) (terminology following (Flegal et al., 2015) estimates the number of cause-specific deaths that would be prevented if the current BMI distributions were changed to a hypothetical alternative distribution; the so-called counterfactual distribution (Danaei et al., 2009). We rewrite equation 2 to show more intuitively how this approach calculates mortality attributable to high BMI (≥23 kg/m²):

$$PAF = \frac{\sum p_1 RR_i - \sum p_2 RR_i}{\sum p_1 RR_i}$$ (Equation 3)

where $p_1$ refers to the observed BMI distribution (the factual distribution), $p_2$ to the counterfactual distribution, and $RR_i$ to the cause-specific relative risk of mortality for exposure level $i$.

Adjustment of the CRA approach

To estimate deaths attributed to obesity only (BMI≥30 kg/m²), we adjusted the CRA calculation to the following:

$$PAF_{BMI≥30} = \frac{\sum_{BMI≥30} p_{1i} \cdot RR_i - \sum_{BMI≥30} p_{2i} \cdot RR_i}{\sum_{i=0}^{\infty} p_{1i} \cdot RR}$$ (Equation 4)

i.e.; we limited the numerator to categories with BMI 30+, while the denominator contains all BMI categories, so that the resulting fraction can be multiplied by the total deaths in a country. As counterfactual we used the BMI range 21-23 kg/m² (GBD 2013 Risk Factors Collaborators, 2015; GBD 2015 Risk Factors Collaborators, 2016).

2.2.2. Data sources

BMI data

Obesity prevalence and BMI distribution (i.e. Mean ± Standard Deviation) data required for the all-cause and the CRA approaches, respectively, were obtained from the Dutch Health Interview Survey (de Wit et al., 2009) from Statistics Netherlands. This is a nationally representative on-going study based on self-reported weight and height, covering the period 1981 to 2013 (de Wit et al., 2009; Centraal Bureau voor de Statistiek, 2018).
**Mortality data**

All-cause mortality data by sex, age group (30-75+), and year (1981 to 2013) were obtained from the Human Mortality Database (HMD) (Human Mortality Database, 2018), and were used for all the approaches.

For the adjusted CRA approach, we obtained cause-specific mortality data by sex and age from the World Health Organization (WHO) Mortality Database (WHO, 2016). In fact, we used two different sets of causes of death and associated RRs (see Table 2.1), and – consequently – distinguish two adjusted CRA approaches: adjusted CRA recent and adjusted CRA less recent. See Table 2.1 for the causes of death used in these two adjusted CRA approaches.

**Relative Risks (RRs)**

Because unadjusted RRs are not readily available, we had to include adjusted RRs for the all-cause approaches, as has previously been done (Allison et al., 1999; Banegas et al., 2003). From the meta-analysis by Flegal et al. (2013), we obtained worldwide and European overall RRs, adjusted for (at least) age and sex; and sex-specific RRs (Flegal et al., 2013). From the meta-analysis by Wang, we obtained age- and sex-specific worldwide RRs (Wang, 2015). From the Dynamo project (Lobstein & Jackson Leach, 2010), which is based on a comprehensive literature review, we obtained European age- and sex-specific RRs (See Table 2.2).
### Table 2.1. Causes of death used in the two adjusted CRA approaches, and the associated RRs at ages 50-54

<table>
<thead>
<tr>
<th>Causes of death</th>
<th>Relative Risks</th>
<th>Causes of death</th>
<th>Relative Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men aged 50-54</td>
<td></td>
<td>Women aged 50-54</td>
</tr>
<tr>
<td>Colon and rectum cancers</td>
<td>1.04</td>
<td>Colon and rectum cancers</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>1.02</td>
<td>Breast cancer</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corpus uteri cancer</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diabetes mellitus</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hypertensive heart disease</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ischemic heart disease</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cerebrovascular disease</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kidney cancer</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pancreatic cancer</td>
<td>1.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Esophageal cancer</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liver cancer</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gallbladder cancer</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leukemia</td>
<td>1.02</td>
</tr>
</tbody>
</table>

* The causes of death we included are the same as those listed by Danaei 2009 (Danaei et al., 2009), except we did not include non-Hodgkin lymphoma.

** The GBD 2013 also uses the following causes of death: hemorrhagic stroke, cardiomyopathy, atrial fibrillation, aortic aneurysm, peripheral vascular endocarditis, other cardiovascular disease, diabetes, chronic kidney disease (CKD), glomerulonephritis CKD, other CKD, hypertensive CKD, ovarian cancer, and thyroid cancer (GBD 2013 Risk Factors Collaborators, 2015). However, because our study period covers causes of death classified by both ICD-9 and ICD-10, and some of the abovementioned detailed causes of death were not available from the WHO mortality database, we restricted ourselves to the causes of death listed here.
### Table 2.2: RRs used in the all-cause approach and their characteristics

<table>
<thead>
<tr>
<th>Approach</th>
<th>Geographical context</th>
<th>Age</th>
<th>RR Men</th>
<th>RR Women</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partially adjusted</td>
<td>Worldwide</td>
<td>All adult ages</td>
<td>1.18</td>
<td></td>
<td>(Flegal et al., 2013)</td>
</tr>
<tr>
<td>Partially adjusted</td>
<td>Europe</td>
<td>All adult ages</td>
<td>1.27</td>
<td></td>
<td>(Flegal et al., 2013)</td>
</tr>
<tr>
<td>Combined approach</td>
<td>Worldwide</td>
<td>All adult ages</td>
<td>1.27</td>
<td>1.25</td>
<td>(Flegal et al., 2013)</td>
</tr>
<tr>
<td>Weighted sum method</td>
<td>Europe</td>
<td>&lt;50</td>
<td>1.55</td>
<td>1.5</td>
<td>(Lobstein &amp; Jackson, 2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-59</td>
<td>1.539</td>
<td>1.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60-69</td>
<td>1.5225</td>
<td>1.475</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>70+</td>
<td>1.495</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>Weighted sum method</td>
<td>Worldwide</td>
<td>&lt;35</td>
<td>1.59</td>
<td>1.60</td>
<td>(Wang, 2015)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35-44</td>
<td>1.39</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>45-54</td>
<td>1.39</td>
<td>1.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>55-64</td>
<td>1.21</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>65-74</td>
<td>1.15</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>75+</td>
<td>1.11</td>
<td>1.11</td>
<td></td>
</tr>
</tbody>
</table>
For our adjusted CRA approach, we used cause-, sex-, and age-specific RRs provided by the GBD 2013, which are worldwide RRs based on a meta-analysis (recent RRs) (GBD 2013 Risk Factors Collaborators, 2015). In addition, we identified previously published worldwide RRs based on a meta-analysis (Danaei et al., 2009) (See Table 2.1).

2.3. Results

The different approaches generated different estimates of the OAMFs for the Netherlands in 2013 (see Table 2.3). Using worldwide RRs, the weighted-sum method provided the lowest estimates for men and women combined (0.92%) and for men (0.86%). However, the partially adjusted method provided a slightly lower estimate for women (0.94%) than the weighted sum method (0.98%). The adjusted CRA approach using the 2013 world RRs generated the highest estimates for men and women combined (1.46%) and for women (1.62%), while the combined all-cause method using the world RRs provided the highest estimate for men (1.43%). The use of European-specific RRs instead of worldwide RRs resulted in higher estimates. The weighted sum method, using the European-specific RRs resulted in the highest estimates overall (1.78%).

Table 2.3. Estimates of the percentage of deaths attributed to obesity, by method and sex, in the Netherlands, 2013

<table>
<thead>
<tr>
<th>Approach</th>
<th>Men</th>
<th>Women</th>
<th>Men and women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partially adjusted – world</td>
<td>0.97</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>Partially adjusted – Europe</td>
<td>1.45</td>
<td>1.37</td>
<td>1.41</td>
</tr>
<tr>
<td>Weighted sum method – world</td>
<td>0.86</td>
<td>0.98</td>
<td>0.92</td>
</tr>
<tr>
<td>Weighted sum method – Europe</td>
<td>1.88</td>
<td>1.68</td>
<td>1.78</td>
</tr>
<tr>
<td>Combined all-cause method – world</td>
<td>1.43</td>
<td>1.29</td>
<td>1.37</td>
</tr>
<tr>
<td>Adjusted CRA, recent – world</td>
<td>1.29</td>
<td>1.62</td>
<td>1.46</td>
</tr>
<tr>
<td>Adjusted CRA, less recent – world</td>
<td>1.21</td>
<td>1.48</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Overall, the different approaches—with the exception of the results for women generated by the CRA approaches—showed that the OAMF levels increased over the period 1981-2013, and especially from 1993 onwards (see Figure 2.1, Table 2.4). For men, the trends are quite parallel for the different approaches, although in terms of percentage change the CRA approaches resulted in larger overall increases (> 75%) (Table 2.4), than the all-cause approaches (around 50%). For women, the trends identified by the adjusted CRA approaches clearly differed from
those found by the other approaches. Over the period 1981-2013, both the adjusted CRA approach with recent RRs and the adjusted CRA with less recent RRs resulted in a decline (-1.7% and -9.6%, respectively), albeit with a slight increase from 1993 onwards (4.3% and 0.7%, respectively). For women, the other approaches estimated the overall percentage increase at around 85%, although the partially adjusted method using European RRs resulted in a larger increase (133%), and the weighted sum method using worldwide RRs in a smaller increase (63%). When applied to men and women combined (Figure S2.1), the partially adjusted method and the weighted sum method produced very similar levels and trends, especially from 1993 onwards. The same was observed for the two CRA approaches.

Table 2.4. Percentage change in obesity-attributable mortality fractions (OAMF) 1981-1993, 1993-2013, 1981-2013, the Netherlands, by sex

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>- Men</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially adjusted - world</td>
<td>-19.1%</td>
<td>78.7%</td>
<td>44.5%</td>
</tr>
<tr>
<td>Partially adjusted – Europe</td>
<td>-14.8%</td>
<td>73.2%</td>
<td>47.5%</td>
</tr>
<tr>
<td>Weighted sum method – world</td>
<td>2.3%</td>
<td>49.3%</td>
<td>52.7%</td>
</tr>
<tr>
<td>Weighted sum method – Europe</td>
<td>-13.6%</td>
<td>74.4%</td>
<td>50.6%</td>
</tr>
<tr>
<td>Combined all-cause method – world</td>
<td>-19.2%</td>
<td>77.8%</td>
<td>43.6%</td>
</tr>
<tr>
<td>Adjusted CRA recent – world</td>
<td>25.3%</td>
<td>56.4%</td>
<td>96.0%</td>
</tr>
<tr>
<td>Adjusted CRA less recent – world</td>
<td>19.5%</td>
<td>48.9%</td>
<td>77.9%</td>
</tr>
<tr>
<td><strong>- Women</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially adjusted - world</td>
<td>0.2%</td>
<td>85.9%</td>
<td>86.4%</td>
</tr>
<tr>
<td>Partially adjusted – Europe</td>
<td>31.5%</td>
<td>77.1%</td>
<td>133.0%</td>
</tr>
<tr>
<td>Weighted sum method – world</td>
<td>-4.8%</td>
<td>70.8%</td>
<td>62.6%</td>
</tr>
<tr>
<td>Weighted sum method – Europe</td>
<td>2.1%</td>
<td>79.5%</td>
<td>83.3%</td>
</tr>
<tr>
<td>Combined all-cause method – world</td>
<td>0.2%</td>
<td>85.2%</td>
<td>85.6%</td>
</tr>
<tr>
<td>Adjusted CRA recent – world</td>
<td>-5.8%</td>
<td>4.3%</td>
<td>-1.7%</td>
</tr>
<tr>
<td>Adjusted CRA less recent – world</td>
<td>-10.3%</td>
<td>0.7%</td>
<td>-9.6%</td>
</tr>
</tbody>
</table>
Figure 2.1. Estimates of the percentage of deaths attributed to obesity in the Netherlands, using worldwide RRs, 1981-2013

- Men

- Women
2.4. Discussion

2.4.1. Summary of results

The different approaches to estimate obesity-attributable mortality fractions (OAMFs) for the Netherlands in 2013 led to a range of estimates. The weighted sum method using worldwide RRs generated the lowest (0.9%), while the adjusted CRA approach using 2013 RRs generated the highest estimate (1.5%). Using European-specific RRs instead of worldwide RRs resulted in higher estimates. Most of the approaches revealed an increasing OAMF over the period 1981-2013, especially from 1993 onwards. However, the adjusted CRA approach showed that there was hardly any increase among women.

2.4.2. Explanation of the observed results

The different approaches we applied—i.e., the partially adjusted method, the weighted sum method, the combined all-cause method, and the adjusted CRA approach—provided different estimates of obesity-attributable mortality. These findings further corroborate previous research showing that PAF estimates vary widely according to the methodology used (Flegal et al., 2015). The plausible explanations for our finding that the estimates produced by the CRA approaches were higher than the estimates generated by the partially adjusted method and the weighted sum method lie not only in the methodology employed, but also in the different underlying data and RRs used. Specifically, in the all-cause approaches, obesity prevalence, all-cause mortality data, and all-cause RRs (Flegal et al., 2004) are used; while in the adjusted CRA approach, more detailed information is used, including data on the whole BMI distribution, cause-specific mortality, and the cause-specific RRs (Kelly et al., 2009). It appears that the combined all-cause method was able to produce similar results based on less detailed information.

Our finding for 2013 that the weighted sum method produced lower OAMF estimates, when worldwide RRs are used, seems to be in line with the results of a study conducted in the US in 1991, which showed that the partially adjusted method generated an OAMF estimate that was 17% higher than the estimate produced by the weighted sum method (Flegal et al., 2004). The explanation given by the researchers is that the partially adjusted method does not fully account for confounding and effect modification by age and sex. It should be noted, however, that in our analysis, the RRs for the partially adjusted method and the weighted sum method
did not come from the same study. This most likely explains why the partially adjusted method actually produced lower estimates than the weighted sum method when the European RRs were used.

In our study, the use of European RRs resulted in higher estimates than the use of worldwide RRs within the same method, primarily because the European RR values were higher than the worldwide RR values (see Table 2.2). Also in previous literature, European RR values were reported to be higher than those from North America, East Asia, Australia, and New Zealand (Banegas et al., 2003; Flegal et al., 2013; Global BMI Mortality et al., 2016). While no clear explanation of these differences in RR values has been provided in the available literature, it most likely follows the notion that RRs could be different for some disease and all-cause mortality across geographical contexts (Lobstein & Jackson Leach, 2010; Preston & Stokes, 2011). In other words, the differences in RR values across populations are likely related to variation in dietary (Li et al., 2015), disease, and mortality patterns, and in genetic background (National Research Council (US) Panel on Race, Ethnicity, and Health in Later Life, 2004).

In our study, all of the approaches (except of the adjusted CRA approach for women) revealed an increase in obesity-attributable mortality levels, especially from 1993 onwards. These findings are in line with the results of previous studies of obesity prevalence and BMI mean values for the Netherlands, which showed that obesity prevalence increased sharply after the 1990s (see Figure S2.2) (Centraal Bureau voor de Statistiek, 2018). In addition, the accelerated increase is in line with the observations for other European adult cohort populations (von Ruesten et al., 2011). Taken together, these findings seem to indicate that the obesity epidemic is accelerating in Netherlands and other European populations. It should be noted, however, that the GBD study found that the trend in mortality due to high BMI in the Netherlands was decreasing over the 1990-2013 period. This seemingly contradictory finding is most likely related to the indirect estimation by the GBD of mean BMI values over time. The declining trend that was found using their indirect estimation (Ng et al., 2014) does not reflect the actual observed trend in the Netherlands (Centraal Bureau voor de Statistiek, 2018).

For women, the adjusted CRA approach clearly resulted in different trends compared to the other approaches, with a decline over the period 1990-2013. Since these differences were not observed for men, the reason for this finding seems to lie less in the methodology that was
applied than in the sex-specific data that were used. Because the RRs do not change over time and are fairly similar for men and women (see Table 2.1), the trends in mean BMI and the trends in cause-specific mortality are more decisive. Specifically, we found that the mean BMI values of women have increased less than the mean BMI values of men in all age groups (see Figure S2.3). Moreover, when we looked at the trends for ischemic and cerebrovascular heart disease, which represent around 70% of the changes in mortality in both sexes, we found that after 1993 ischemic and cerebrovascular mortality declined more among women than among men.

2.4.3. Reflection on our approach

When aiming to compare the different methodologies to estimate obesity-attributable mortality and their estimates concerning Europe, data availability is a major restricting factor. Related to this, we chose a practical and rather straightforward evaluation strategy where we compared the methodologies that can practically be applied with the available data and their point estimates.

Each available method requires a different level of detail as regards the RR (by age group or not, by cause of death or not). Unfortunately, a dataset providing all the RRs needed is not available. Instead, we, like previous studies, had to rely on RRs from different data sources/meta-analyses for each method (Flegal et al., 2015). The comparison of levels is likely to generate different outcomes (different differences) when, in a simulation study, hypothetical RRs from one source are used. The comparison of trends will, however, likely be much less affected because distorting factors presumably lead to larger RR differences between sources than within sources over time. More importantly, however, when the method is applied in practice it will do so based on the available RRs.

Also, we chose not to estimate confidence intervals surrounding the RRs. Firstly, due to using secondary data (from different sources, and both for RR and prevalence), we do not possess the covariance matrix of the relevant variables, hence formal comparison of levels or trends cannot be made unless untestable assumptions -which will affect the comparisons- are also made (Flegal et al., 2015). Secondly, in standard frequentist approaches, confidence intervals cannot capture all the uncertainty surrounding the estimation of obesity-attributable mortality. For instance, they cannot assess the uncertainty regarding the choice of the RR.
Thirdly, policy makers, public health professionals, and researchers working on obesity-attributable mortality in Europe mostly merely use point estimates.

Although we used a fairly simple evaluation approach, still it is the first time that the influence of the chosen method (and the related RRs) on obesity-attributable mortality trends for a European country has been assessed. In doing so, our study provided valuable insights into the pros and cons of the different methods and highlighted as well the urgency for additional data in Europe.

2.4.4. Reflection on the different methodologies

We applied methodologies that, based on their data requirements, enabled us to construct time series of the OAMF. We included three all-cause approaches: the partially adjusted method, the weighted sum method, and a combined all-cause method. The partially adjusted method requires the least amount of detailed data. However, because of the scarcity of unadjusted RRs, most studies that have applied this method (including our study) used adjusted RRs instead (Allison et al., 1999; Banegas et al., 2003), which can produce biased estimates (Flegal et al., 2004). To limit this bias, we used the combined all-cause method, which enabled us to weight by sex. We also applied the weighted sum method, which allowed us to take into account both confounding and effect modification by age and sex using age- and sex-specific RRs. As the weighted sum method deals with confounding and effect modification better than the other all-cause methods we examined, it seems to be the most appropriate method to use for the estimation of OAMF. In fact, the results produced by the weighted sum method, using European RRs, were close to the results generated in 2013 by the adjusted CRA method.

In addition, we applied the CRA approach, which we adjusted to estimate the share of mortality due to obesity only. An advantage of the CRA approach is that it has the potential to provide more reliable estimates because it takes more information into account; namely, information on the obesity-related causes of death. One disadvantage of the CRA approach is that it requires the BMI distribution and data on (detailed) causes of death, which are not readily available for European countries. This issue is especially salient when aiming to study time trends. In addition, the changes in the ICD classification over time (Janssen & Kunst, 2004)
make it difficult to obtain the complete list of causes of death associated with obesity over time.

Given these considerations, we recommend the use of the weighted sum method for the study of trends in OAMFs for the European context and ideally the provision of confidence intervals.

2.5. Conclusions

Estimates of both the levels of, and the trends in, obesity-attributable mortality fractions in the Netherlands differed depending on the method applied, as well as on the underlying data and the relative risks (RRs) used. Because obesity prevalence is relatively low in the Netherlands, we would expect to find even larger differences for countries with higher obesity prevalence. In quantifying the health burden of obesity at the population level, it is therefore essential to compare different methodologies and different RRs.

Comparisons of obesity-attributable mortality between countries and over time can only be performed accurately using one and the same methodology, and comparable data and RRs. As the data that are currently available for Europe are limited, we recommend using the weighted-sum method and European RRs to compare obesity-attributable mortality across European countries and over time.
References


Human Mortality Database. (2018). University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Retrieved from [http://www.mortality.org](http://www.mortality.org)


Impact of different estimation methods on obesity-attributable mortality | 61


Supplementary Material 1 Chapter 2

To identify the available methods for calculating obesity-attributable mortality by means of the Population Attributable Fraction (PAF), we searched the US National Library of Medicine Gateway system, PubMed Central, and PubMed to identify the relevant published literature using the following search terms: obesity or BMI or body-mass-index and attributable or PAF or attributable and mortality. After reviewing the available literature, we identified five different PAF formulas for estimating obesity-attributable mortality; each formula requiring different data (see Table S2.1). We divided the methods into those that use relative risks (RRs) for all-cause mortality (all-cause approach) and those that use RRs for obesity-related causes of death (cause-of-death approach).

Table S2.1. Methods to estimate the obesity-attributable mortality fraction (OAMF) by means of different PAF formulas and their data requirements

<table>
<thead>
<tr>
<th>Type of method</th>
<th>Formula used to calculate PAF</th>
<th>Required data</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause approach, Allison DB et al. 1999 and Banegas JR 2003 (Allison et al., 1999; Banegas et al., 2003)</td>
<td>PAF = ( P \cdot \frac{(RR - 1)}{1 + P \cdot (RR - 1)} )</td>
<td>Proportion of population exposed to obesity (P); Relative risk (RR) of mortality associated with obesity, not adjusted for confounding.</td>
</tr>
<tr>
<td>Cause-of-death approach, Farzadfar F et al. 2011 (Farzadfar et al., 2011)</td>
<td>PAF = ( \sum p_{1i}RR_i - \sum p_{2i}RR_i ) ( \sum p_{1i}RR_i )</td>
<td>Observed BMI distribution (Mean ± Standard Deviation) (p_{1i}); Counterfactual BMI distribution (p_{2i}^*); Cause-specific relative risks (RR) of mortality corresponding to obesity level i.</td>
</tr>
<tr>
<td>All-cause approach, Flegal KM 2005 (Flegal et al., 2005)</td>
<td>PAF = ( \frac{M - M^<em>}{M} ) where M = I( \sum p_{i}RR_i ) M^</em> = I( \sum p_{i}RR_i^* )</td>
<td>Population baseline mortality rate (I); Relative risks (RR_i) corresponding to each combination of BMI level and the levels of the accounted covariates for each age-group (i); Counterfactual relative risk (RR_{i}^*) when BMI is set to the reference level but other risk factors are left unchanged;</td>
</tr>
</tbody>
</table>
### Table S2.1. (Continued)

<table>
<thead>
<tr>
<th>Type of method</th>
<th>Formula used to calculate PAF</th>
<th>Required data</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-cause approach,</td>
<td>PAF = ( P_d \cdot \frac{(RR - 1)}{RR} )</td>
<td>Prevalence of BMI-risk factor combinations (p&lt;sub&gt;i&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Katzmarzyk PT et al. 2004</td>
<td></td>
<td>Proportion of the deceased exposed to obesity (P&lt;sub&gt;d&lt;/sub&gt;);</td>
</tr>
<tr>
<td>(Katzmarzyk &amp; Ardern, 2004)</td>
<td></td>
<td>Relative risk (RR) of mortality associated with obesity, adjusted for relevant confounders</td>
</tr>
<tr>
<td>All-cause approach,</td>
<td>PAF&lt;sub&gt;ik&lt;/sub&gt; = ( pd_{ik} \cdot (HRoverweight_{k} - 1)/HRoverweight_{k} ) + ( pd_{ij} \cdot ((HRgrade1_{k} - 1)/HRgrade1_{k}) ) + ( pd_{ik} \cdot ((HRgrade23_{k} - 1)/HRgrade23_{k}) )</td>
<td>Fraction of total deaths that are exposed to the ith 5-year birth cohort at age k (pd&lt;sub&gt;i&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Masters RK et al. 2013</td>
<td></td>
<td>Hazard ratio of overweight mortality risk to normal weight mortality risk at age k (HRoverweight&lt;sub&gt;i&lt;/sub&gt;)</td>
</tr>
<tr>
<td>(Masters et al., 2013)</td>
<td></td>
<td>Hazard ratio of grade 1 obesity mortality risk to normal weight mortality risk at age k (HRgrade1&lt;sub&gt;i&lt;/sub&gt;)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hazard ratio of grade 2/3 obesity mortality risk to normal weight mortality risk at age k (HRgrade23&lt;sub&gt;i&lt;/sub&gt;)</td>
</tr>
</tbody>
</table>

† If the counterfactual BMI distribution or the counterfactual relative risk is theoretical, instead of the distribution or relative risk of e.g. a comparison group, it is not strictly speaking an empirical data requirement.
Supplementary Material 2 Chapter 2

Figure S2.1. Estimates of the percentage of male and female deaths combined attributed to obesity in the Netherlands, using world RRs, 1981-2013

Figure S2.2. Age-standardized obesity prevalence by sex, 20-75+ yrs. in the Netherlands, 1981-2013
Figure S2.3. BMI Mean values, 30-79 years, the Netherlands, 1981-2013

- Men

- Women
Table S2.2. PAF estimates compared in men and women for the Netherlands 1981, 1991, 2001 and 2013, and 1981-2013

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially adjusted - world</td>
<td>0.67%</td>
<td>0.50%</td>
<td>0.54%</td>
<td>0.86%</td>
<td>0.97%</td>
</tr>
<tr>
<td>Partially adjusted – Europe</td>
<td>0.98%</td>
<td>0.74%</td>
<td>0.84%</td>
<td>1.27%</td>
<td>1.45%</td>
</tr>
<tr>
<td>Weighted sum method – world</td>
<td>0.56%</td>
<td>0.51%</td>
<td>0.57%</td>
<td>0.83%</td>
<td>0.86%</td>
</tr>
<tr>
<td>Weighted sum method – Europe</td>
<td>1.25%</td>
<td>0.95%</td>
<td>1.08%</td>
<td>1.65%</td>
<td>1.88%</td>
</tr>
<tr>
<td>Combined all-cause method – world</td>
<td>1.00%</td>
<td>0.75%</td>
<td>0.81%</td>
<td>1.27%</td>
<td>1.43%</td>
</tr>
<tr>
<td>Adjusted CRA, recent – world</td>
<td>0.66%</td>
<td>0.75%</td>
<td>0.82%</td>
<td>1.16%</td>
<td>1.29%</td>
</tr>
<tr>
<td>Adjusted CRA, less recent – world</td>
<td>0.68%</td>
<td>0.77%</td>
<td>0.81%</td>
<td>1.12%</td>
<td>1.21%</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially adjusted - world</td>
<td>0.50%</td>
<td>0.59%</td>
<td>0.51%</td>
<td>0.85%</td>
<td>0.94%</td>
</tr>
<tr>
<td>Partially adjusted – Europe</td>
<td>0.59%</td>
<td>0.89%</td>
<td>0.77%</td>
<td>1.27%</td>
<td>1.37%</td>
</tr>
<tr>
<td>Weighted sum method – world</td>
<td>0.60%</td>
<td>0.62%</td>
<td>0.58%</td>
<td>0.95%</td>
<td>0.98%</td>
</tr>
<tr>
<td>Weighted sum method – Europe</td>
<td>0.92%</td>
<td>1.08%</td>
<td>0.94%</td>
<td>1.56%</td>
<td>1.68%</td>
</tr>
<tr>
<td>Combined all-cause method – world</td>
<td>0.70%</td>
<td>0.81%</td>
<td>0.70%</td>
<td>1.17%</td>
<td>1.29%</td>
</tr>
<tr>
<td>Adjusted CRA, recent – world</td>
<td>1.64%</td>
<td>1.93%</td>
<td>1.55%</td>
<td>1.83%</td>
<td>1.62%</td>
</tr>
<tr>
<td>Adjusted CRA, less recent – world</td>
<td>1.64%</td>
<td>1.74%</td>
<td>1.47%</td>
<td>1.71%</td>
<td>1.48%</td>
</tr>
</tbody>
</table>
Past trends in obesity-attributable mortality in eight European countries: an application of age–period–cohort analysis

Abstract:

Objectives: To assess age, period, and birth cohort effects and patterns of obesity-attributable mortality in Czech Republic, Finland, France, Germany, Hungary, Italy, Poland, and United Kingdom (UK).

Methods: We obtained obesity prevalence and all-cause mortality data by age (20-79), sex and country for 1990-2012. We applied Clayton and Schifflers’ age-period-cohort approach to obesity-attributable mortality rates (OAMRs).

Results: Between 1990 and 2012, obesity prevalence increased and age-standardized OAMRs declined, although not uniformly. The nonlinear birth cohort effects contributed significantly (p<0.01) to obesity-attributable mortality trends in all populations, except in Czech Republic, Finland, and among German women and Polish men. Their contribution was greater than 25% in UK and among French women, and larger than that of the nonlinear period effects. In the UK, mortality rate ratios (MRRs) increased among the cohorts born after 1950. In other populations with significant birth cohort effects, MRRs increased among the 1935-1960 cohorts and decreased thereafter.

Conclusions: Given its potential effects on obesity-attributable mortality, the cohort dimension should not be ignored and calls for interventions early in life next to actions targeting broader societal changes.

Key words: obesity, mortality, birth cohort, APC analysis, Europe
3.1. Introduction

Obesity has increased dramatically in recent decades, and is now considered a global epidemic (Finucane et al., 2011). While the United States (US) still has the highest obesity prevalence (OECD, 2014) (36.5% in 2011-2014) Europe ranks second (Eurostat, 2017), with national prevalence levels ranging from 10% to 30% (Eurostat, 2017). Obesity has major consequences for individual and for population health, as it increases the risk of a range of diseases (Field et al., 2001; Calle & Kaaks, 2004), and consequently the risk of dying (Global BMI Mortality Collaboration, 2016). In order to set effective health policy priorities it is essential to study the obesity epidemic and gain an understanding of how it evolved over time (Finucane et al., 2011).

Previous studies that examined time trends in obesity prevalence have provided valuable insight into how the epidemic evolved, the differences that exist across countries and between men and women, and the underlying factors (Finucane et al., 2011). Previous studies that focused on estimating the health burden of obesity by assessing obesity-attributable mortality; were mostly conducted in the US (Allison et al., 1999; Flegal et al., 2005; Mehta & Chang, 2009) and to a lesser extent in Europe (Banegas et al., 2003; Kelly et al., 2009), and did not assess trends over time. To the best of our knowledge, only one previous study has examined the long-term trends in the share of mortality due to obesity in Canada indicating that this share increased over time (Katzmarzyk & Ardern, 2004).

Few of the aforementioned studies took into account the multiple dimensions of the obesity epidemic: namely, age, period, and birth cohort (Reither et al., 2009). It is well known that age affects obesity, as declining levels of physical activity and physiological changes occur with increasing age (Starling, 2001; Reither et al., 2009). In addition, broad societal changes, such as the increase of sedentary lifestyles and the consumption of high-calorie foods, have contributed to increases in obesity over calendar time (period effects) (Popkin, 2006; Reither et al., 2011; Masters et al., 2013). However, differences in the obesity prevalence levels among people born in different years (i.e., (birth) cohort effects) exist as well (Reither et al., 2011).

Birth cohort membership is important because it could indicate the degree to which individuals are receptive to societal and social changes (Hellevik, 2002; Reither et al., 2009). Compared to older birth cohorts, younger birth cohorts are more likely to have a high-calorie
diet and a sedentary lifestyle, largely because they are more receptive to using modern technologies, products, and media (Reither et al., 2009). Birth cohort effects may also reflect long-lasting effects of exposures earlier in life (Janssen & Kunst, 2005). A growing body of evidence indeed shows that excess fat in adolescence or early adulthood and weight gain over the life course have long-term implications for metabolic, cardiovascular, and mortality risk (Must et al., 1992; Franks et al., 2010; Yu, 2012). Because of these long-lasting effects, birth cohort dynamics are key to understanding the future of health and longevity (Masters et al., 2013).

The few previous studies that have applied age-period-cohort (APC) analyses to obesity prevalence found that age, period, and cohort effects were all important (Diouf et al., 2010; Jiang et al., 2013; Masters et al., 2013). While there are no APC analyses of obesity-attributable mortality, Yu applied APC analysis to mortality differentials associated with body mass (Yu, 2012), and Masters estimated obesity-attributable mortality by birth cohort, and found more deaths among younger than older birth cohorts (Masters et al., 2013). However, neither study focused on Europe.

Our study is the first to assess age, period, and birth cohort effects and patterns in past obesity-attributable mortality trends in Europe.

3.2. Methods

3.2.1. Design

We estimated obesity-attributable mortality trends from 1990 to 2012 for the adult populations of eight European countries: the Czech Republic, Germany, Finland, France, Hungary, Italy, Poland, and the UK.

To warrant the data quality, we included only European countries for which the trends in obesity prevalence, which we obtained from the Global Burden of Disease (GBD) study (Ng et al., 2014), revealed similar patterns as those based on data from the Organisation for Economic Co-operation and Development (OECD, 2018). Also, we ensured that the included countries comprise the four different European regions and differ in terms of the levels, patterns and trends in obesity prevalence. To ensure that the obesity prevalence data and the all-cause mortality data were closely aligned, we restricted our analysis to the period 1990-
Past trends in obesity-attributable mortality in eight European countries

2012. We focused on the adult population aged 20-79, because the prevalence data had 80+ as the final open-ended age category with unknown upper. The combination of ages 20-79 and calendar years 1990-2012 resulted in the inclusion of the birth cohorts from 1911 to 1992 (cohort = period – age).

3.2.2. Data

Estimated obesity prevalence data (BMI≥30kg/m²) (WHO, 1998) were obtained from the GBD study by country, five-year age groups, sex, and single calendar year for the period 1990-2012 (Ng et al., 2014). These data were generated by using a spatiotemporal regression and a Gaussian process regression, which allow dealing with the available prevalence data from different sources and missing data (Ng et al., 2014).

We obtained all-cause death numbers and exposure population numbers by country, sex, five-year age groups and year from the Human Mortality Database (Human Mortality Database, 2018).

3.2.3. Analysis

We performed all of our analyses separately for men and women.

Obesity-attributable mortality

To calculate the obesity-attributable mortality fractions by country, year, age and sex, that we shall refer to as obesity- attributable mortality fraction (OAMF), we used the Rockhill formula for the population-attributable fraction (PAF) (Rockhill et al., 1998):

$$\frac{OAMF_{a,s}}{\text{year}} = \frac{P_{a,s} \cdot (RR - 1)}{1 + P_{a,s} \cdot (RR - 1)}$$

where $P_{a,s}$ is the obesity prevalence in five-year age group $a$ and sex $s$ by country and year and $RR$ is the relative risk of mortality associated with obesity (Rockhill et al., 1998). We used the RR from a recent meta-analysis based on European studies that adjusted for at least age, sex, and smoking (Flegal et al., 2013). In using an adjusted RR in the Rockhill formula we basically applied the “partially adjusted method” for estimating PAFs (Flegal et al., 2004). Because the sex differences in the RRs were only marginal, we used the overall RR of 1.27 (Flegal et al., 2013).
Age- and sex-specific obesity-attributable mortality deaths were estimated by multiplying age- and sex-specific with OAMF by the corresponding deaths. All-age obesity-attributable mortality fractions were obtained by dividing the sum of age-specific obesity-attributable mortality deaths by the total deaths for each sex.

The obesity-attributable mortality rates (OAMRs) were obtained by dividing the age-, and sex-specific obesity-attributable deaths by the corresponding exposure populations. These five-year age group obesity-attributable mortality rates were subsequently turned into single age-specific mortality rates by applying two-dimensional P-splines smoothing (Camarda, 2012).

**Descriptive analysis**

The age-specific obesity-attributable mortality rates by birth cohort were depicted in graphs, where we have selected single ages five years apart, to improve the visual clarity. The obesity-attributable mortality rates and obesity prevalence levels were directly age-standardized to ensure their comparability across countries, thereby using the sex-specific European population of 2011 as a standard (Eurostat, 2011).

**Age-period-cohort (APC) modelling**

We applied age-period-cohort (APC) modelling to obesity-attributable mortality rates. The section below follows largely the APC methodology, as described by Bijlsma et al. (Bijlsma et al., 2012).

In modelling the obesity-attributable mortality rates as a function of age, period, and birth cohort, the linear dependency between the three variables \((a = p - c)\) needs to be taken into account to avoid over-identification. We therefore applied the standard Clayton and Schifflers approach (Clayton & Schifflers, 1987a; Clayton & Schifflers, 1987b). This method, which has been used in previous demographic (Janssen & Kunst, 2005) and epidemiological studies (Dhillon et al., 2011; Bijlsma et al., 2012), distinguishes between age effects, the effect of the shared linearity of period and birth cohort (referred to as drift), the nonlinear period effects, and the nonlinear birth cohort effects.

We applied four Poisson regression models to obesity-attributable death numbers for each county and sex combination, setting the natural logarithm of the exposure population as an offset term. The age (A) model is defined by: \(\ln[m_a] = \mu + \alpha_a\); The age-drift (AD) model is
defined by $\ln[m_{ad}] = \mu + \alpha_a + \delta$; The age-period (AP) model is defined by $\ln[m_{ap}] = \mu + \alpha_a + \beta_p$; and the age-period-cohort (APC) model is defined by $\ln[m_{apc}] = \mu + \alpha_a + \beta_p + \gamma_c$. Where $m$ is the obesity-attributable mortality rate, $\mu$ is the intercept, $\alpha$, $\beta$ and $\gamma$ represent the age, period and birth cohort effects, and $\delta$ represents the drift (Janssen & Kunst, 2005).

We used as constraints two categories of birth cohorts, as this approach allowed us to estimate and visualise the nonlinear birth cohort effects separately from the linear time trend changes. As reference categories we used age 50, calendar year 2000, and the 1935 and 1970 birth cohorts Age 50 and calendar year 2000 represent the middle observations of our data (1990-2012; 20-79). The two reference categories for the cohort dimension were chosen so that they do not refer to the extreme birth cohorts with fewer observations, but still lie as much apart as possible so as to separate a long-term linear trend from the non-linear deviations of that trend (Bijlsma et al., 2012; Trias-Llimos et al., 2017). For comparative purposes we used the same reference categories for all countries and both sexes in our analysis.

To determine the statistical contribution of birth cohort to observed trends and levels, we compared the goodness of fit of age (A), age-drift (AD), age-period (AP), and age-period-cohort (APC) for the different models. Using the deviance statistic, a measure of goodness of fit, we performed both likelihood ratio tests of the A, AD, AP and APC models to the data, and likelihood ratio tests for model reduction. Due to our interest in birth cohorts, the primary comparison for the model reduction tests was APC with AP, but we also compared AD with A and AP with AD. Reduction in deviance is expressed as percentage reduction in deviance between the age-only model and the APC model. In our graphs we show the cohorts born between 1920 and 1980, as observations for more extreme cohorts were less complete. All of the data analyses were performed using R 3.2.5 in R studio 0.99.451.

3.3. Results

Over the calendar years 1990-2012, age-standardized obesity prevalence increased among the adult populations in all eight countries, albeit not to the same extent (Figure 3.1). The biggest increases were in the UK, followed by Finland and Germany. In the Czech Republic, France, Poland, Italy, Hungary, and Germany (women only), rising obesity periods were accompanied by periods in which a levelling off occurred. Age-standardized obesity
prevalence was generally higher among women than men. In 2012, obesity prevalence was highest in the UK (26%), and was lowest (less than 20%) in Italy and among men in the Czech Republic and Poland.

The trends in the sex-specific obesity-attributable mortality fraction (OAMF) look similar to the trends in age-standardized obesity prevalence except for Hungarian and Polish women (see Figure S3.1). In 2012, the share of all-cause mortality due to obesity ranged from 5.43% (France) to 7.07% (UK) among men, and from 4.85% (France) to 8.21% (Germany) among women. Between 1990 and 2012, the OAMF increased in all of the countries except in Hungary and among Polish women, albeit not to the same extent.

Over time, the age-standardized obesity-attributable mortality rates (OAMRs) declined in all of the populations studied, although not uniformly (Figure 3.2). The pace of the decline was relatively fast in Hungary, the Czech Republic, and Poland; but was relatively moderate throughout the period in Finland, Germany and Italy. Among French women and British men and women, the OAMRs increased prior to 2000. Over the same period, the age-standardized all-cause mortality rates decreased faster than the age-standardized OAMRs (see Figure S3.2).
Past trends in obesity-attributable mortality in eight European countries

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Figure 3.1. Age-standardized obesity prevalence trends by sex in populations aged 20-79 years in eight European countries, 1990-2012
Figure 3.2. Age-standardized obesity-attributable mortality rates (OAMRs) by sex in populations aged 20-79 years in eight European countries, 1990-2012

For the majority of the countries the age-specific obesity-attributable mortality rates showed an overall decline across birth cohorts. However, for the UK especially we observed increasing obesity-attributable mortality rates across younger birth cohorts (Figure 3.3).

Our modelling of the obesity-attributable mortality trends showed that, in addition to the age effects, both the nonlinear period effects and the nonlinear cohort effects proved to be significant (see Table 3.1). The contribution of the nonlinear birth cohort effects to the obesity-attributable mortality trends was statistically significant (p-values<0.01) among French, Hungarian, Italian, and British men and women and among German men and Polish women (Table 3.1). For all sex-specific populations, the APC models provided a good fit to the data (p-values > 0.999) (see Table S3.1).
Figure 3.3. Age-specific obesity-attributable mortality rates (OAMRs) by birth cohort (1911-1992) (log scale) and sex, in populations aged 20-79 years in eight European countries, 1990-2012
Table 3.1. Model reduction (log-likelihood ratio) test of the age-drift, age-period and age-period cohort models by sex in populations aged 20-79 years in eight European countries, 1990-2012

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<td>Age period (AP)</td>
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<td>Age period cohort (APC)</td>
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Log-likelihood ratio test of model reductions in deviance comparing AD to A, AP to AD and APC to AP (p-value): Statistical significance at p-value < 0.05, ** p-value < 0.01
The contribution of the nonlinear birth cohort effect to the model fit ranged from 1.60% (Czech Republic) to 57.9% (UK) in men and in women from 0.25% (Czech Republic) to 28% (France). The largest contribution of the nonlinear birth cohort effects was among British men (57.9%), while the nonlinear birth cohort contributed more than 25% to the deviance reduction among French and British women. In all of the countries and among both men and women, the contribution of the nonlinear birth cohort effects was larger than the contribution of the nonlinear period effects. The drift made the largest contribution to the deviance reduction, exceeding 75% in all countries and among both men and women, except in the UK and among French women (Figure 3.4).

In the UK, obesity-attributable mortality rate ratios started to increase among the cohorts born after 1950 (Fig. 3.5). This trend was followed by a slight decline among British men born after 1975. In the remaining populations with significant cohort effects (German men; Polish women; and French, Hungarian, and Italian men and women), mortality rate ratios increased among the cohorts born between 1935 and 1960, and decreased among the cohorts born after 1960.

**Figure 3.4.** Contribution of the drift, the non-linear period effect and the non-linear cohort effect to the deviance reduction between the age model and the age-period-cohort model applied to obesity-attributable mortality by sex in populations aged 20-79 years in eight European countries, 1990-2012.
3.4. Discussion

3.4.1. Summary of results

Between 1990 and 2012, obesity prevalence increased and OAMRs declined in the eight European countries studied, albeit with notable differences across countries, between men and women, and over time. Throughout, the APC models provided a good data fit (p>0.999). Nonlinear birth cohort effects contributed significantly (p<0.01) to the obesity-attributable mortality trends in all of the countries studied, except in the Czech Republic, Finland, Germany (women), and Poland (men). The contribution of these effects was greater than 25% in the UK and among French women, and was larger than the nonlinear period effects. However, drift, the linear component of the period and the cohort, was the largest contributor, except among British men. In general, obesity-attributable mortality rate ratios decreased among the subsequent birth cohorts, except among the cohorts born after 1950 in UK and among the cohorts of German men; Polish women; and French, Hungarian, and Italian men and women born between 1935 and 1960.
3.4.2. Evaluation of data and methods

In estimating the share of mortality due to obesity (OAMF), we were hampered by data limitations regarding prevalence and RRs. As obesity prevalence trends were different for different sources, we restricted our analysis to countries for which the obesity prevalence trends from the GBD (Ng et al., 2014) were similar to those by the OECD (OECD, 2018). Secondly, and in line with previous studies, we applied adjusted RRs to the Rockhill formula, originally developed for the use of non-adjusted RRs (Flegal et al., 2004), as unadjusted RR were not readily available. Thirdly, the method we used was driven by the availability of data. Although other methods to estimate PAF could have affected the obesity-attributable mortality levels, they would not have affected the trends. Fourthly, because RRs of dying from obesity are not available by country and year, we applied one time-constant European-specific RR (Flegal et al., 2013). A sensitivity analysis where we applied the only available information on declines in RR from the US (Mehta et al., 2014) revealed that this primarily affected drift and period trends, and had no influence on the observed non-linear cohort trends.

Smoking is importantly affecting overall mortality levels and trends (Thun et al., 2012) and could therefore bias our estimate of obesity-attributable mortality which we obtain by multiplying the obesity-attributable mortality fraction with all-cause mortality. A sensitivity analysis in which we applied our obesity-attributable mortality fractions to non-smoking-related mortality (Janssen et al., 2013) resulted however in almost identical cohort patterns.

To differentiate between the age, period, and cohort effects, we used the often-applied Clayton and Schifflers approach (Clayton & Schifflers, 1987a; Clayton & Schifflers, 1987b). By separately modelling the shared linearity of the period and birth cohort effects (referred to as drift), this approach enabled us to estimate the nonlinear period effects and the nonlinear birth cohort effects. The resulting contributions are however underestimates of the complete period and cohort effects, which comprise both the non-linear effects and the linear effects which are embedded in the drift. Especially when drift is large—as it is in our study—the underestimation can be substantial.

The choice of constraints within the APC analysis indeed has the potential to affect the patterns of age, period and cohort, but not the relative importance of their non-linear contributions (Figure 3.4). A sensitivity analysis, in which we applied two alternative sets of
cohort constraints (see Figure S3.3, S3.4) revealed that our estimated cohort patterns proved in general robust, albeit less so for Hungary and Finland. Therefore our results and main conclusion were not affected by the choice of constraints.

3.4.3. Explanation of the results

The decline in the age-standardized OAMRs that we observed might look counterintuitive at first, given the general increase we found in the age-standardized obesity prevalence and in the OAMFs. The more rapid decline of age-standardized all-cause mortality rates compared to the decline in obesity-attributable mortality rates indicates that while obesity indeed had an impact on mortality trends, the observed increase in the OAMFs could not compensate for the greater overall decline in the all-cause mortality rates. For the US similar declines in obesity-attributable mortality were observed (Flegal et al., 2005; Mehta & Chang, 2009).

Our results show that the cohort dimension is important. Especially for the UK, we were able to demonstrate that nonlinear birth cohort effects made a large contribution to obesity-attributable mortality trends, especially among men (58%) but also among women (27%). The strong cohort effect for the UK can be linked to the finding that more recent UK birth cohorts developed greater probabilities of overweight or obesity at younger ages (Johnson et al., 2015). The observed cohort effect also seems to be another indicator of the further progression of the obesity epidemic in the UK compared to other European countries, next to the higher obesity levels and the sharper increase in obesity prevalence over time (Lifestyles statistics team, Health and Social Care Information Centre, 2014). The cohort patterns for the UK show that obesity-attributable mortality has been increasing among the cohorts born after 1950, which was also reflected in the age-specific obesity-attributable mortality rates by cohorts (Figure 3.5).

A similar birth cohort pattern in obesity-attributable mortality rates was observed in the US (Masters et al., 2013). The consistently lower overweight and obesity prevalence in the UK compared to the US, combined with a more rapid recent increase (Public Health England, 2016) illustrate that the UK is still in the upward dynamic of the obesity epidemic, but that the US is further ahead. In both phases of the obesity epidemic the cohort dimension thus is important. The evidence showing that there are strong cohort effects and increasing trends in
Past trends in obesity-attributable mortality in eight European countries

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The cohort patterns for the populations among whom the cohort effects were significant—German men; Polish women; and French, Hungarian, and Italian men and women—reveal that the OAMRs increased among the cohorts born between 1935 and 1960, and decreased among the cohorts born after 1960. This cohort pattern is not in line with the increasing levels of receptivity in younger birth cohorts, brought by societal and social changes (Reither et al., 2009). A more likely explanation for the observed increase is that the cohorts born around the time of the Second World War experienced food restrictions even in utero. Poor gestational nutrition may have led to metabolic adaptations of the foetus, thereby increasing the propensity of these cohorts to become obese in adulthood, particularly in an obesogenic environment (Hales & Barker, 2001; Wells, 2007; Pico et al., 2012).

3.4.4. Overall conclusion and implications

Next to age and period effects on obesity-attributable mortality, we also observed cohort effects. The substantial birth cohort effect for the UK, with increases in obesity-attributable mortality for those born after 1950, indicates that the UK is following the trajectory of the US in the obesity epidemic. Other European countries will likely follow the footsteps of UK and US, unless action is being taken. The presence of a cohort effect, reflecting effects that happen early in the life-course with long-lasting outcomes, calls for interventions early in life next to actions targeting societal changes which represent period effects.

The cohort dimension should not be ignored in future studies. It provides an important element in our understanding of complex public health problems such as obesity-attributable mortality. Moreover, it can facilitate targeted actions to birth cohorts at elevated risks and – in line with the ageing of current cohorts - inform future obesity-attributable mortality levels.
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Supplementary Material Chapter 3

**Figure S3.1.** Trends in obesity-attributable mortality fractions by sex in populations aged 20-79 years in eight European countries, 1990-2010

![Graph showing trends in obesity-attributable mortality fractions by sex in eight European countries, 1990-2010.](image)

**Figure S3.2.** Age-standardized all-cause mortality rates by sex in populations aged 20-79 years in eight European countries, 1990-2012

![Graph showing age-standardized all-cause mortality rates by sex in eight European countries, 1990-2012.](image)
Sensitivity analysis of the non-linear birth cohort patterns in which two additional sets of cohort constraints were used

**Figure S3.3.** Nonlinear birth cohort patterns by sex in populations aged 20-79 years in eight European countries, 1990-2012. Cohort references 1925, 1975, Period and age reference were kept the same (age=50, calendar year=2000).

**Figure S3.4.** Nonlinear birth cohort patterns by sex in populations aged 20-79 years in eight European countries, 1990-2012. Cohort references 1940, 1980, Period and age reference were kept the same, age=50, calendar year=2000.
Table S3.1. Model fit to data (log-likelihood ratio) test comparing all models to the data by sex in populations aged 20-79 years in eight European countries, 1990-2012

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Log-likelihood ratio test comparing model to the data

Statistical significance at p-value< 0.05, **p-value<0.01
Impact of obesity on life expectancy among different European countries, 1975-2012


Manuscript submitted for publication, current status: revise and resubmit.
Abstract:

**Background:** Previous studies on the impact of obesity on life expectancy focused on the United States or a single calendar year. We assessed the impact of obesity on life expectancy for 26 European national populations and the USA over the 1975-2012 period.

**Methods:** Using data by age and sex, we calculated obesity-attributable mortality by multiplying all-cause mortality (Human Mortality Database) with obesity-attributable mortality fractions (OAMFs). OAMFs were obtained by applying the weighted sum method to obesity prevalence data (NCD Risk Factor Collaboration) and European Relative Risks (RRs) (DYNAMO). We estimated potential gains in life expectancy (PGLE) by eliminating obesity-attributable mortality using associated single-decrement life tables.

**Results:** In the 26 European countries in 2012, PGLE due to obesity ranged from 0.86 to 1.67 years among men, and from 0.66 to 1.54 years among women. In all countries, PGLE increased over time, with an average annual increase of 2.68% among men and 1.33% and among women. Among women in Denmark, Switzerland, and Central and Eastern European countries, the increase in PGLE levelled off after 1995. Without obesity, the average increase in life expectancy between 1975 and 2012 would have been 0.78 years higher among men and 0.30 years higher among women.

**Conclusions:** Obesity was proven to have an impact on both life expectancy levels and trends in Europe. The differences found in this impact between countries and the sexes can be linked to contextual factors, as well as to differences in people’s ability and capacity to adopt healthier lifestyles.

**Keywords:** Obesity, life expectancy, Europe, USA
4.1. Introduction

Obesity is a global epidemic (Finucane et al., 2011), with Europe currently ranking second worldwide after the USA (Eurostat, 2017). Over the last 20 years obesity prevalence has increased threefold in Europe (WHO, 2007), although not uniformly across countries (Seidell, 2002). Estimates for 2014 indicate that obesity varied threefold across European countries, ranging from a low of 9% in Romania to a high of 26% in Malta (Eurostat, 2016). Obesity constitutes a serious health burden at the individual and population levels because it is associated with an increased risk of morbidity (Field et al., 2001), and mortality (Global BMI Mortality Collaboration et al., 2016). However, the potential impact of the increase in obesity on life expectancy trends remains largely unknown (Alley et al., 2011).

The few existing studies that assessed the impact of obesity on life expectancy at the population level provided estimates at one specific point in time only (Olshansky et al., 2005; Preston & Stokes, 2011). Olshansky et al. (2005) found that if obesity was eliminated, life expectancy at birth (e0) in the USA in 2000 would be 0.21 to 1.08 years higher, depending on gender and ethnicity (Olshansky et al., 2005). Preston et al. (2001) estimated for 16 low-mortality countries in 2006 that the reduction in life expectancy at age 50 (e50) due to obesity was greatest in the USA, at more than 1.5 years; and ranged from 0.50 to 1.19 years for women and from 0.72 to 1.37 years for men in European countries.

Gaining insight into the impact of obesity on trends in life expectancy is especially relevant (National Research Council, 2011) given the marked differences in life expectancy trends across Europe (Leon, 2011). In Western European countries, e0 has been increasing steadily, and has risen six to eight years since 1970. But in Central and Eastern Europe (CEE), e0 stagnated or even declined between the 1970s and the 1980s, and did not start increasing again until the 1990s. There are also marked differences in e0 trends between individual European countries (Leon, 2011).

In light of these important differences between European countries in both obesity prevalence and life expectancy over time, our aim is to assess the impact of obesity on long-term trends in life expectancy across a wide range of European countries.
4.2. Data and Methods

4.2.1. Setting

We studied the impact of obesity on life expectancy by sex over the 1975-2012 period in 26 European countries: Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom (UK); and the USA as a comparison country (Preston & Stokes, 2011).

4.2.2. Data

Obesity prevalence data (BMI ≥ 30 kg/m²) by country, sex, age (18-19, 20-24, ..., 85+), and year (1975-2012) were obtained from the NCD Risk Factor Collaboration study (2016). These validated data comprise the available height and weight data supplemented with estimates based on information from other years and related countries from a Bayesian hierarchical model (NCD Risk Factor Collaboration, 2016).

The age- (<50, 50-59, 60-69 and ≥70 years) and sex-specific relative risks (RRs) of dying from obesity (see Table S4.1) came from a review of studies mainly conducted in Western Europe and the USA (Lobstein & Leach, 2010). These age- and sex-specific RRs were largely in line with the overall European RR of 1.64 recently estimated by the Global BMI Mortality Collaboration (Global BMI Mortality Collaboration et al., 2016).

All-cause mortality numbers and exposure population data by single year of age, sex, and year were obtained from the Human Mortality Database (Human Mortality Database, 2018).

4.2.3. Methods

We performed our analyses separately by country and sex, based on data by single year of age (18-100). The obesity prevalence data were turned into single-age prevalence (18-100) by applying Loess smoothing (Cleveland & Loader, 1995). The RRs were turned into single-year RRs (18- 100) using linear regression.

To estimate the obesity-attributable mortality fraction (OAMF) – i.e., the share of all-cause mortality due to obesity – we used the Rockhill formula to estimate OAMFs by age (a) and sex (s) (Rockhill et al., 1998).
Impact of obesity on life expectancy among different European countries, 1975-2012

4.2. Data and Methods

4.2.1. Setting
We studied the impact of obesity on life expectancy by sex over the 1975-2012 period in 26 European countries: Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom (UK); and the USA as a comparison country (Preston & Stokes, 2011).

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\[
OAMF_{a,s} = \frac{P_{a,s} \cdot (RR_{a,s} - 1)}{1 + (P_{a,s} \cdot (RR_{a,s} - 1))}
\]

(Equation 1)

where P is the obesity prevalence. We then weighted the OAMF_{a,s} with the corresponding number of deaths.

For the estimation of the impact of obesity on life expectancy (see 2.3.2) we needed age-and sex-specific (non-) obesity-attributable mortality rates. These were obtained by multiplying OAMF_{a,s} and [1- OAMF_{a,s}], respectively, with age- and sex-specific all-cause mortality rates.

To ensure comparability across countries, over time, and between men and women, we applied direct age- and sex-standardisation (Preston et al., 2001) to obesity prevalence, obesity-attributable mortality fractions, and obesity-attributable mortality rates, using the European population of 2011 (Eurostat, 2011) as the standard.

To assess the impact of adult obesity on e₀, we calculated for each country the potential gain in life expectancy (PGLE) if obesity-attributable mortality were eliminated, by calendar year and sex. First, we calculated e₀ by applying standard life table techniques to age-specific all-cause mortality rates (Preston et al., 2001). Second, we applied associated single-decrement life tables (ASDLT) (Preston et al., 2001) to age- and sex-specific non-obesity-attributable mortality rates to obtain e₀ if obesity-attributable mortality were eliminated. The PGLE represents the difference between the e₀ based on the ASDLT and the original e₀.

To summarise the changes in PGLE across countries, we estimated the average annual changes in PGLE (in %):

\[
Average\ annual\ changes\ in\ PGLE\ (\%) = \sum_{t=1976}^{2012} \frac{(PGLE_t - PGLE_{t-1})}{PGLE_{t-1}} \cdot \frac{2012 - 1975}{100}
\]

To assess the impact of obesity on time trends in e₀ between 1975 and 2012, we subtracted the observed change in e₀ from the change in e₀ without obesity. The change in e₀ without obesity was obtained by using the e₀ values from the associated single-decrement life tables applied to non-obesity-attributable mortality for 1975 and 2012.

4.3. Results

For the 26 European countries, the age-standardized obesity-attributable mortality fraction (OAMF) was, on average, 11% among men and 10% among women in 2012. For the USA, these
estimates were substantially higher; i.e., 15% and 14%, respectively. The average OAMF levels were higher in Northern, Western, and Southern Europe combined (hereafter, Western Europe) than in CEE among men, while the opposite was the case among women.

OAMFs were increasing over time for all countries and both sexes, although not to the same extent (see Figure 4.1 and S4.1). In Western Europe, OAMFs generally increased over the 1975-2012 period, and at a faster pace among men. In CEE, by contrast, OAMFs clearly stagnated, and even declined between 1990 and 2000. The overall increase in OAMFs was greatest in the USA, Ireland, Norway (men), and the UK (women).

In the 26 European countries in 2012, estimates of potential gains in life expectancy at birth (PGLE) if obesity was eliminated ranged from 0.86 to 1.67 years among men (1.22 on average) and from 0.66 to 1.54 years (0.98 on average) among women (Figure 4.2, S4.2 and Table S4.2). Among men in the USA, the PGLE estimate was, at 1.73 years, slightly higher than the highest estimate in Europe; and among women in the USA, the PGLE estimate was, at 1.44 years, the second-highest after the estimate for Russia. The average PGLE estimate was 1.08 among men and 0.86 among women in Western Europe, and was 1.44 among men and 1.16 among women in CEE (see Table S4.2).

Overall, from 1975 to 2012, PGLE due to obesity increased in all of the countries (Figure 4.2, S4.2 and 4.3). The increase was greater among men (average annual increase of 2.68%) than among women (average annual increase of 1.33%), was largest among men in Portugal and Belarus and among women in Portugal, and was substantial among men and women in Norway (Figure 4.3). While there was a general increase in PGLE due to obesity, this trend stagnated among women in CEE from around 1990 onwards, and levelled off after 1995 among women in Denmark and Switzerland.

Table 4.1 shows the impact of obesity on time trends in life expectancy at birth (e0). Overall, the average increase in e0 between 1975 and 2012 was 7.26 years for men and 6.28 years for women in the 26 European countries. Without obesity, the average increase in e0 would have been 8.04 years for men and 6.58 years for women; or 0.78 and 0.30 years higher, respectively. Among men, obesity had the greatest impact on e0 trends in Lithuania and the USA (more than one year), and the smallest impact in Iceland and Sweden (0.5 years). Among women, obesity had the greatest impact on e0 trends in the USA and Ireland (0.7 years) and the smallest impact in Estonia and the Czech Republic (less than 0.1 year).
Figure 4.1. Age-standardized obesity-attributable mortality fractions in 26 European countries (by 5 regions) and USA, 1975-2014, 18-100 years

Countries within the same region are presented with the same colour

Central Europe: Czech Republic, Hungary, Poland, Slovakia

Eastern Europe: Belarus, Estonia, Ukraine, Latvia, Lithuania, Russian Federation

Northern Europe: Denmark, Finland, Iceland, Norway, Sweden

Southern Europe: Italy, Portugal, Spain

Western Europe: Austria, Belgium, France, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom

USA: United States of America
Figure 4.2. Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality was eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the USA, 1975-2012, 18-100 years

Countries within the same region are presented with the same colour

Central Eastern Europe: Belarus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Russian Federation, Slovakia, Ukraine

Western Europe: Austria, Belgium, Denmark, Finland, France, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom

USA: United States of America
Figure 4.3. Average annual increase (%) in potential gains in life expectancy due to obesity in 26 European countries and the USA between 1975-2012, by sex

- **Men**

- **Women**
### Table 4.1. Impact of obesity on trends in life expectancy at birth ($e_0$) in 26 European countries and USA 1975-2012, by sex

<table>
<thead>
<tr>
<th>Country</th>
<th>Change in $e_0$ with obesity 2012-1975 (years)</th>
<th>Change in $e_0$ without obesity 2012-1975 (years)</th>
<th>Effect of obesity on $e_0$ change 2012-1975 (years)</th>
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<td>Women</td>
<td>Men</td>
</tr>
<tr>
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<td>Average Western countries</td>
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<td>7.09</td>
<td>9.76</td>
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</table>
4.4. Discussion

4.4.1. Summary of results

In the 26 European countries studied, the share of mortality due to obesity in 2012 was, on average, 11% among men and 10% among women. PGLE due to obesity in 2012 ranged from 0.86 to 1.73 years among men, and from 0.66 to 1.54 years among women. Overall, PGLE increased between 1975 and 2012, albeit more quickly among men (average annual increase: 2.68%) than among women (1.33%). Among women in Denmark, Switzerland, and the CEE countries the increase in PGLE levelled off after 1995. Without obesity, the average increase in e0 between 1975 and 2012 would have been 0.78 years higher among men and 0.30 years higher among women.

4.4.2. Evaluation of data and methods

Using the recent advances in obesity data, it is now possible to study the impact of obesity on life expectancy for a large number of countries and a long period of time. Two methodological issues warrant our attention, however.

First, in calculating the share of mortality due to obesity (OAMF), which also forms the basis for our PGLE calculations, we were hindered by limitations in the available prevalence and RRs data, which also affected the method used. As has previously been documented, OAMF estimates are sensitive to the data and the methods used (Flegal et al., 2015).

In selecting obesity prevalence data, we used the longest available validated time series suitable for studying the impact of obesity on long-term life expectancy trends across Europe (NCD Risk Factor Collaboration, 2016). For those countries with less available obesity data – especially CEE countries – a portion of the data we used were modelled, and these should be treated with some caution (NCD Risk Factor Collaboration, 2016).

Because age- and sex-specific RRs of mortality associated with obesity are not available by country and year, we applied to all of the countries studied time-constant age- and sex-specific RRs from Western European and US populations that are largely suitable for our setting. However, literature for the USA has demonstrated that RRs have been changing over time, pointing to both a decline (Flegal et al., 2005; Mehta & Chang, 2011; Yu, 2012) and an increase (Yu, 2016). Before implementing time-variant European RRs, more information on their direction is required. Similarly, comparable country-specific RRs are urgently needed.
Based on the available data, only a fairly easy method could be applied to estimate the OAMFs, which is referred to as the weighted sum (Flegal et al., 2015). The application of another methodology (Flegal et al., 2015) could have affected the OAMFs and thus the PGLE levels, but less the trends (Vidra et al., 2018).

Second, besides being the result of the OAMFs, the PGLE estimates can also be affected by all-cause mortality levels and trends as age- and sex-specific all-cause mortality rates are used to estimate PGLE. Since all-cause mortality fluctuated greatly in CEE in the analysed period (Leon, 2011), short-term variations in PGLE in CEE countries should be treated with more caution.

### 4.4.3. Explanation of results

In 2012, the PGLE due to obesity were, on average, 1.22 years for men and 0.98 years for women in the 26 European countries, and 1.73 years for men and 1.43 years for women in the USA. A comparison of our 2006 e50 estimates with those of Preston et al. (2001) for the same countries uncovered only small differences, except among men in the USA (our estimate was 0.56 years lower) and women in the UK (our estimate was 0.29 years lower) (see Table S4.3). Given that approximately the same methodology was used to estimate the OAMFs, the observed differences are most likely due to the use of different obesity prevalence and RRs data. Preston used prevalence data from national representative surveys and RRs from the Prospective Studies collaboration (Lobstein & Leach, 2010).

To further evaluate our observed PGLE levels, we compared them with own PGLE estimates for smoking and alcohol (Trias-Llimós et al., 2017). Our PGLE estimates for smoking were 2.38 years for men and 1.00 year for women in Western Europe, and 3.82 years for men and 0.67 years for women in CEE. Our PGLE estimates for alcohol were 0.90 years for men and 0.44 years for women in Western Europe, and 2.15 years for men and 1.00 year for women in CEE (Trias-Llimós et al., 2017). Thus, obesity’s impact on life expectancy lies between that of smoking and alcohol, and can be considered significant.

In our study, we found that PGLE due to obesity was increasing, but that this trend differed across countries and between the sexes. This overall trend can be explained by the general increase in obesity prevalence in European countries (see Figure S4.3) (NCD Risk Factor Collaboration, 2016) and the resulting growth in the burden of obesity (WHO, 2007), which is also reflected in the OAMFs (Figure 4.1, S4.1) in these countries.
At the same time, parts of the observed variation in the increase in PGLE estimates across the USA, Western Europe, and CEE and between the sexes reflect differences in the onset, the development, and the impact of the obesity epidemic in these countries and in men and women. Across the countries studied, the absolute increase in PGLE was largest among women and second-largest among men in the USA. This pattern is in line with evidence showing that between 1980 and 2008, obesity increased much more in the USA than in Europe (Finucane et al., 2011; Doak et al., 2012). This rapid progression of the obesity epidemic in the USA and its large impact on life expectancy has been attributed to an increasingly obesogenic environment caused by factors such as changes in food preparation and processes that promote the consumption of calorically dense foods, and a pronounced decrease in physical activity levels (Cutler et al., 2003). The obesity epidemic has progressed more slowly in Western Europe than in the USA (Finucane et al., 2011; NCD Risk Factor Collaboration, 2016).

However, obesity levels in countries like the UK and Ireland are rapidly approaching those in the USA (OECD, 2012), as our PGLE estimates also show.

In the CEE countries, the PGLE trends track the evolution of the obesity epidemic in that region (see Figure S4.3). Obesity levels have been higher in CEE than in Western Europe since 1980 (Silventoinen et al., 2004; Malik et al., 2013), which suggests that the epidemic started earlier in CEE. As a result of this earlier onset, the impact of obesity (as expressed in terms of OAMF and PGLE) in the 1970s and 1980s was at times even greater in CEE than in the USA, especially among women. While there are many potential explanations for this early onset of the obesity epidemic in CEE, the available data indicate that the main factors were the relatively high total energy supply and energy intake in CEE in those years (Zatonski & Bhala, 2012).

The overall progress of the obesity epidemic was lower in CEE than in Western Europe, and the increase was not constant (Finucane et al., 2011). Indeed, in CEE, increases in obesity prevalence (Bray & Bouchard, 2003; Finucane et al., 2011), OAMFs, and PGLE stagnated in the 1980-2008 period, more pronounced in the 1990s (Bray & Bouchard, 2003; Finucane et al., 2011). This pattern could be explained by the decrease in energy supplies at the beginning of the 1990s in CEE (Silventoinen et al., 2004) resulting from the dramatic economic and political changes in those countries (Bray & Bouchard, 2003; Silventoinen et al., 2004; Finucane et al., 2011). Among CEE women, the increase in obesity starting in the 1990s was smaller than it was in the previous period, and was smaller than it was among CEE men. The lower risk of
obesity observed among women than among men with low socioeconomic status (SES) in low-income countries (Monteiro et al., 2004) may explain this difference.

In Western Europe, a stagnation in PGLE levels was observed among women in Denmark and Switzerland after 1995. This finding seems to be in line with studies reporting a levelling-off of mean BMI since the 1990s (Wilkins et al., 2017); and in specific sub-populations, such as adults with high SES in regions within Switzerland, Italy, France, and Finland (Silventoinen et al., 2004). Although dietary and physical activity information is spreading equally across socioeconomic groups, those with higher SES have a greater ability and capacity to adopt a healthier dietary and physical activity pattern (Robertson et al., 2007). In addition, it appears that higher SES women in particular are more health-conscious, have healthier food habits, and are more prone to follow nutritional recommendations (Fagerli & Wandel, 1999) as they are under greater social pressure to be thin (Psaltopoulou et al., 2017). Similarly, countries with higher income levels and lower levels of inequality (WHO, 2014), like Switzerland and Denmark, tend to have lower obesity levels, especially among women.

When we considered the impact of obesity on life expectancy in the 26 European countries, we found that without obesity, the increase in e0 between 1975 and 2012 would have been, on average, 0.78 years higher among men and 0.30 years higher among women. These figures account for approximately 10% of the average change in e0 between 1975 and 2012 among men, and 5% among women. It is therefore clear that the impact of obesity on changes in e0 should not be ignored. Moreover, the impact of obesity on life expectancy trends is likely to increase, given that this impact is already substantially greater in the USA (13% among men and 15% among women), and that obesity prevalence is still increasing rapidly in most European countries (see Figure S4.3).

4.5. Conclusion and implications

Obesity was proven to have an impact on both life expectancy levels and trends in Europe. The observed differences in the increase in the impact of obesity across countries and between the sexes reflect differences in the onset and the progression of the obesity epidemic, and can be linked to contextual factors (economic conditions, obesogenic environment, energy supplies), as well as to differences in people’s ability and capacity to adopt healthier lifestyles.
It is likely that in the future obesity will have a larger impact on mortality and life expectancy in Europe, as obesity continues to increase in the majority of countries. It is therefore crucial that effective public health initiatives are undertaken to tackle the obesity epidemic and its effects on public health. Such initiatives should address the multifactorial and complex obesity aetiology; the clear differences between countries and the sexes; as well as the factors underlying these differences, such as contextual factors and differences in individuals’ ability and capacity to adopt healthier lifestyles.
References


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WHO. (2014). *Obesity and inequities. guidance for addressing inequities in overweight and obesity*. Copenhagen, Denmark: World Health Organization.


### Table S4.1. Age-and sex-specific RRs of dying from obesity from the Dynamo project (Lobstein et al. 2010)

<table>
<thead>
<tr>
<th>Age</th>
<th>RR Men</th>
<th>RR Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>1.55</td>
<td>1.5</td>
</tr>
<tr>
<td>50-59</td>
<td>1.539</td>
<td>1.49</td>
</tr>
<tr>
<td>60-69</td>
<td>1.5225</td>
<td>1.475</td>
</tr>
<tr>
<td>70+</td>
<td>1.495</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Reference group for the RRs: normal weight (18-24.9 kg/m²)
Figure S4.1. Age-standardized obesity-attributable mortality fractions in 26 European countries, grouped by 5 regions and USA, 1975-2014, 18-100 years

Countries within the same region are presented with the same colour.
Figure S4.2. Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality was eliminated, in 26 European countries, grouped by 2 regions and USA, 1975-2012, 18-100 years

Countries within the same region are presented with the same colour
Table S4.2. Potential gains in life expectancy at birth (PGLE) if obesity-attributable mortality was eliminated, in 26 European countries (differentiating Western and Central Eastern Europe) and the USA, in 1975 and 2012, 18-100 years

<table>
<thead>
<tr>
<th>Country</th>
<th>PGLE 1975</th>
<th></th>
<th>PGLE 2012</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td><strong>Central Eastern Europe (CEE)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belarus</td>
<td>0.41</td>
<td>0.79</td>
<td>1.41</td>
<td>1.19</td>
</tr>
<tr>
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<td>0.70</td>
<td>0.98</td>
<td>1.39</td>
<td>1.03</td>
</tr>
<tr>
<td>Estonia</td>
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<td>1.00</td>
<td>1.37</td>
<td>1.04</td>
</tr>
<tr>
<td>Hungary</td>
<td>0.64</td>
<td>0.86</td>
<td>1.52</td>
<td>1.04</td>
</tr>
<tr>
<td>Latvia</td>
<td>0.58</td>
<td>1.00</td>
<td>1.48</td>
<td>1.18</td>
</tr>
<tr>
<td>Lithuania</td>
<td>0.54</td>
<td>1.05</td>
<td>1.67</td>
<td>1.31</td>
</tr>
<tr>
<td>Poland</td>
<td>0.57</td>
<td>0.93</td>
<td>1.48</td>
<td>1.19</td>
</tr>
<tr>
<td>Russian Federation</td>
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<td>1.53</td>
<td>1.54</td>
</tr>
<tr>
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<td>1.31</td>
<td>0.96</td>
</tr>
<tr>
<td>Ukraine</td>
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<td>1.25</td>
<td>1.16</td>
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<tr>
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<td>1.44</td>
<td>1.16</td>
</tr>
<tr>
<td><strong>Western Europe</strong></td>
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<td></td>
<td></td>
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<td>0.39</td>
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<td>Belgium</td>
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<td>0.61</td>
<td>1.17</td>
<td>0.97</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.42</td>
<td>0.46</td>
<td>1.04</td>
<td>0.79</td>
</tr>
<tr>
<td>France</td>
<td>0.49</td>
<td>0.53</td>
<td>1.18</td>
<td>0.84</td>
</tr>
<tr>
<td>Finland</td>
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<td>0.90</td>
</tr>
<tr>
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<td>0.31</td>
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<td>1.01</td>
</tr>
<tr>
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</tr>
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<td>1.19</td>
<td>0.79</td>
</tr>
<tr>
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<td>0.88</td>
</tr>
<tr>
<td>Norway</td>
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<td>1.07</td>
<td>0.91</td>
</tr>
<tr>
<td>Portugal</td>
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<td>0.41</td>
<td>1.01</td>
<td>0.81</td>
</tr>
<tr>
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<td>0.66</td>
<td>1.22</td>
<td>1.05</td>
</tr>
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<td>Sweden</td>
<td>0.42</td>
<td>0.43</td>
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<td>0.93</td>
<td>0.66</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.53</td>
<td>0.50</td>
<td>1.27</td>
<td>1.09</td>
</tr>
<tr>
<td>Average Western Europe</td>
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<tr>
<td><strong>USA</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Average European countries</td>
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<td>0.64</td>
<td>1.22</td>
<td>0.98</td>
</tr>
<tr>
<td>Average all countries</td>
<td>0.47</td>
<td>0.64</td>
<td>1.23</td>
<td>1.00</td>
</tr>
</tbody>
</table>
### Table S4.3. Potential gains in life expectancy at age 50 (PGLE) if obesity-attributable mortality was eliminated, own and Preston estimates, in the same countries studied, in 2006

<table>
<thead>
<tr>
<th>Country</th>
<th>PGLE e50 2006, own estimates</th>
<th>PGLE e50 2006, Preston’s estimates</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>0.81</td>
<td>1.00</td>
<td>-0.19</td>
</tr>
<tr>
<td>Belgium</td>
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<td>0.98</td>
<td>-0.03</td>
</tr>
<tr>
<td>Czech Republic</td>
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<td>1.34</td>
<td>-0.20</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.88</td>
<td>0.82</td>
<td>0.06</td>
</tr>
<tr>
<td>France</td>
<td>0.94</td>
<td>0.99</td>
<td>-0.05</td>
</tr>
<tr>
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<td>0.88</td>
<td>0.90</td>
<td>-0.02</td>
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<td>Netherlands</td>
<td>0.69</td>
<td>0.73</td>
<td>-0.04</td>
</tr>
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<td>Poland</td>
<td>1.14</td>
<td>1.37</td>
<td>-0.23</td>
</tr>
<tr>
<td>Spain</td>
<td>1.02</td>
<td>1.15</td>
<td>-0.13</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.75</td>
<td>0.72</td>
<td>0.03</td>
</tr>
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<td>Switzerland</td>
<td>0.77</td>
<td>0.79</td>
<td>-0.02</td>
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<tr>
<td>United Kingdom</td>
<td>0.99</td>
<td>1.34</td>
<td>-0.35</td>
</tr>
<tr>
<td>USA</td>
<td>1.29</td>
<td>1.85</td>
<td>-0.56</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>0.62</td>
<td>0.71</td>
<td>-0.09</td>
</tr>
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<td>Belgium</td>
<td>0.86</td>
<td>0.73</td>
<td>0.13</td>
</tr>
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<td>Czech Republic</td>
<td>0.87</td>
<td>1.01</td>
<td>-0.14</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.71</td>
<td>0.62</td>
<td>0.09</td>
</tr>
<tr>
<td>France</td>
<td>0.72</td>
<td>0.52</td>
<td>0.2</td>
</tr>
<tr>
<td>Italy</td>
<td>0.84</td>
<td>0.57</td>
<td>0.27</td>
</tr>
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<td>Netherlands</td>
<td>0.76</td>
<td>0.69</td>
<td>0.07</td>
</tr>
<tr>
<td>Poland</td>
<td>1.08</td>
<td>1.19</td>
<td>-0.11</td>
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<td>Spain</td>
<td>0.95</td>
<td>0.87</td>
<td>0.08</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.67</td>
<td>0.63</td>
<td>0.04</td>
</tr>
<tr>
<td>Switzerland</td>
<td>0.59</td>
<td>0.50</td>
<td>0.09</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.94</td>
<td>1.23</td>
<td>-0.29</td>
</tr>
<tr>
<td>USA</td>
<td>1.18</td>
<td>1.28</td>
<td>-0.10</td>
</tr>
</tbody>
</table>
**Figure S4.3.** Age-standardized obesity prevalence in 26 European countries, grouped by 2 regions and USA, 1975-2012, 18-100 years

Countries within the same region are presented with the same colour.
Forecasting obesity in 18 European countries and the United States using the underlying epidemic wave pattern

This chapter is based on: Vidra, N., Bardoutsos, A., & Janssen, F. (2018). Forecasting obesity in 18 European countries and the United States using the underlying epidemic wave pattern.
Abstract:

Background: Obesity is considered an epidemic, yet previous obesity forecasts did not take the underlying wave pattern into account, and mainly considered the short-term future and the United States (US). We will forecast obesity prevalence in the long-term future using the underlying epidemic wave pattern in 18 European countries and the US.

Data & Methods: Our approach – implemented using the Lee-Carter forecasting technique – projects for each country the speed of change of the logit of the age- (20-84) and sex-specific obesity prevalence for 1975-2016, linearly into the future.

Results: In 2016, the age-standardized obesity prevalence ranged from 19.5% (Swiss women) to 39.5% (US women). Over the 1990-2016 period, the increases in obesity prevalence declined. Obesity is expected to reach maximum levels among men from 2030 to 2052, and among women from 2026 to 2054. These levels should be reached first in the Netherlands, the US, and the UK; and last in Switzerland. The maximum levels are expected to be highest in the US (44%) and the UK (37%) and lowest in the Netherlands (28% among men) and in Denmark (24% among women). In 2060, obesity is projected to range from 13.1% (Dutch men) to 36.9% (Swiss men). As in the past, the projected age-specific obesity prevalence levels have an inverse U-shape peaking around ages 60-69.

Conclusions: Using our novel approach, obesity prevalence is expected to reach a maximum between 2026 and 2054, with the US (44%) and the UK (37%) reaching the highest maximum levels first, followed by other European countries.
5.1. Introduction

Obesity increased dramatically over the last four decades (Finucane et al., 2011). While the United States (US) currently ranks first in obesity prevalence levels (36.5% in 2011-2014) (OECD, 2014), the rapid rate of obesity increase in Europe puts the continent in second place globally (average prevalence of 15.9% across EU member states in 2014) (Eurostat, 2016).

Although it took some time for obesity to be recognized as a major public health problem in Europe (WHO, 1998), it is increasingly seen as an important concern among European public health policy-makers (WHO, 2018). As the question of how obesity will evolve in the future is viewed as especially pressing (WHO, 2018), studies that could shed light on obesity's likely evolution in Europe are warranted.

Obesity is characterized by many scholars as an epidemic (Abelson & Kennedy, 2004). The use of this term has some drawbacks, as it disguises some of the characteristics of obesity, such as the endemic character of and the difficulties in defining or accomplishing an end to obesity’s development. But this term appears to fit given the sharp and sudden increases in obesity, often to record-high levels (Flegal, 2006).

A distinct characteristic of epidemics is that they develop in a wave pattern (Lopez et al., 1994; Cliff & Haggett, 2006; Thun et al., 2012; Bresee & Hayden, 2013). In its initial stages, an epidemic increases slowly, and then more quickly. After reaching a plateau, the epidemic declines, more intensely in the beginning and more slowly toward the end. This wave pattern has, for instance, been observed in the smoking (Lopez et al., 1994) and influenza epidemics (Bresee & Hayden, 2013). Very recently, it has been proposed as a theoretical framework to describe the obesity epidemic and its likely evolution (Xu & Lam, 2018).

Indeed, some existing evidence on the evolution of obesity up to now supports the notion that obesity is following the underlying wave pattern of the epidemic. Several studies have reported a stagnation or a levelling off of the obesity increase in countries like the US (Rokholm et al., 2010), Russia, the former Yugoslavia, the Czech Republic, and Lithuania (Silventoinen et al., 2004). In addition, the stabilization of obesity trends has been observed in specific sub-populations, such as adults with high socioeconomic status in regions of Switzerland, France, and Finland (Visscher et al., 2015).
However, previous obesity forecasts did not consider obesity to be evolving as an epidemic. Most provided only short-term projections up to 2020-2030 (McPherson et al., 2007; Ruhm, 2007; Wang et al., 2008 Finkelstein et al., 2012), with, to the best of our knowledge just one providing projections up to 2050 (Butland et al., 2007). Many previous studies on this topic applied linear forecasts that assume that obesity will increase continuously (Butland et al., 2007; McPherson et al., 2007; Ruhm, 2007; Wang et al., 2008). Several recent studies took into account the recent evidence indicating that obesity prevalence may be levelling off, and projected a lower increase up to 2030 (Finkelstein et al., 2012), or a plateau in some countries in 2022 or 2030 (Schneider et al., 2010; Thomas et al., 2014). Moreover, most of these studies were focused on the US, while only a few forecasted future obesity levels in European countries (Schneider et al., 2010, Butland et al., 2007, Pineda et al., 2018). Thus, there is a lack of long-term forecasts of obesity trends for Europe.

This study therefore aims to forecast obesity into the long-term future using a novel approach that incorporates the underlying wave pattern of the epidemic, and will do so for 18 European countries and the US.

### 5.2. Data and Methods

#### 5.2.1. Setting

We forecasted how obesity will evolve in the future for the national populations, aged 20-84, in the US and 18 non-Eastern European countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. We excluded Central and Eastern European countries as their past obesity trends are more irregular (Abarca-Gómez et al., 2017).

#### 5.2.2. Data

Obesity prevalence data (BMI≥30kg/m²) by country, sex, age (20-24, ..., 85+), and year (1975-2016) were obtained from the NCD Risk Factor Collaboration study (Abarca-Gómez et al., 2017). These data comprise the available measured height and weight data, supplemented with estimates from a Bayesian hierarchical model based on information from other years and related countries. We choose this dataset over the 2016 NCD data (NCD Risk Factor Collaboration, 2016) and the data by Ng M 2014 (Ng et al., 2014), as it was based on more observations. We converted the obesity prevalence data for five-year age groups (point
estimates) into single-age prevalence (20-84) by applying Loess smoothing (Cleveland & Loader, 1995).

5.2.3. Approach

Our forecasting approach uses the underlying idea of the obesity epidemic, which is generally represented as a wave pattern that increases slowly in the beginning, and then more strongly; levels off at a maximum level; then declines strongly, followed by a levelling off of the decline (Xu & Lam, 2018).

To incorporate the epidemic wave pattern in our approach, we will focus on differences in the speed of change of the logit of obesity prevalence between successive years (=velocity)(=first order difference). A wave pattern is obtained when the velocity declines linearly over time, namely, from a positive to a negative speed of change; while the maximum level is obtained when the speed of change over time becomes zero for the first time. That is, we require a constant negative acceleration (=second-order difference).

5.2.4. The model

We implemented the epidemic idea in the benchmark projection method in demography; i.e., the Lee-Carter methodology (Shang et al., 2011; Janssen et al., 2013; Janssen, 2018; Lee & Carter, 1992). We then applied it to the logistic transformation of obesity, i.e. the logit of obesity prevalence, to ensure that the projected prevalence remains between 0 and 1 (Lee & Carter, 1992).

The Lee-Carter (LC) model decomposes the logarithm of age-specific mortality rates into a time-invariant age component \( \alpha_x \) which is the average age pattern of mortality, an overall time trend \( \kappa_t \), which is the average rate of change of mortality across all ages, the magnitude of the age-specific change over time \( \beta_x \) and the residual error \( \epsilon_{x,t} \) (Lee & Carter, 1992).

When applying the Lee-Carter to the logistic transformation of obesity prevalence, \( \logit OP_{x,t} \), at age \( x \) and year \( t \), the formula reads as (Equation 1) (Lee & Carter, 1992):

\[
\logit OP_{x,t} = \alpha_x + \beta_x \cdot \kappa_t + \epsilon_{x,t} \quad \text{(Equation 1)}
\]

The model fitted our data well (Table S5.1).
5.2.5. The forecast

The obesity forecast is obtained by linearly extrapolating the velocity of obesity into the future. In other words, we extrapolate the obesity change (=the $\kappa_t$ parameter in our model) by means of a second-order random walk (RW(2)) with negative drift (Hyndman, 2018). Before doing so, however, we implemented lower limits for the projection of period parameter $\kappa_t$ by means of the observed country- and sex-specific obesity prevalence levels in 1975 and the transformation: $f_t = \log(\kappa_t - \kappa_{t_{\text{min}}})$, where $t_{\text{min}}$ is the year 1975.

Based on a careful study of past obesity trends (see Figure 5.1) we decided eventually to extrapolate the transformed period parameter $f_t$ using only data from 2000 onwards, for which we observed a smaller increase in acceleration than we did for the data before 2000.

We forecasted age- and sex-specific obesity prevalence until 2100, and we estimated 95% projection intervals by performing 100,000 simulations. To obtain future overall obesity prevalence levels, we applied direct age standardization using the country- and sex-specific population age compositions in 2014 from the Human Mortality Database (Human Mortality Database, 2018).

5.3. Results

In the 18 European countries in 2016, the age-standardized obesity prevalence ranged from 22.7% in Portugal to 29.3% in the UK for men, and from 19.5% in Switzerland to 31.3% in the UK for women. The age-standardized obesity prevalence was even higher in the US, at 37.5% for men and 39.5% for women.

Between 1975 and 2016, obesity increased in all the studied countries, although not uniformly (Figure 5.1). Especially among women, we observed a recent slowing of the increase in obesity prevalence, particularly in Finland, Greece, and Spain; and, less recently, in Switzerland (Figure 5.1). Our analysis of the change in the logit of obesity prevalence between years – i.e., the velocity – from 1990 onwards (see Figure S5.1) indicates that an overall decline was observed for all countries. This finding indicates that the increase in obesity prevalence is slowing down.
The obesity forecast is obtained by linearly extrapolating the velocity of obesity into the future. In other words, we extrapolate the obesity change (the $\kappa_t$ parameter in our model) by means of a second-order random walk (RW(2)) with negative drift (Hyndman, 2018). Before doing so, however, we implemented lower limits for the projection of period parameter $\kappa_t$ by means of the observed country- and sex-specific obesity prevalence levels in 1975 and the transformation:

$$f_t = \log(\kappa_t - \kappa_{t\min})$$

where $t_{\min}$ is the year 1975. Based on a careful study of past obesity trends (see Figure 5.1) we decided eventually to extrapolate the transformed period parameter $f_t$ using only data from 2000 onwards, for which we observed a smaller increase in acceleration than we did for the data before 2000.

We forecasted age- and sex-specific obesity prevalence until 2100, and we estimated 95% projection intervals by performing 100,000 simulations. To obtain future overall obesity prevalence levels, we applied direct age standardization using the country- and sex-specific population age compositions in 2014 from the Human Mortality Database (Human Mortality Database, 2018).

### 5.3. Results

In the 18 European countries in 2016, the age-standardized obesity prevalence ranged from 22.7% in Portugal to 29.3% in the UK for men, and from 19.5% in Switzerland to 31.3% in the UK for women. The age-standardized obesity prevalence was even higher in the US, at 37.5% for men and 39.5% for women.

Between 1975 and 2016, obesity increased in all the studied countries, although not uniformly (Figure 5.1). Especially among women, we observed a recent slowing of the increase in obesity prevalence, particularly in Finland, Greece, and Spain; and, less recently, in Switzerland (Figure 5.1). Our analysis of the change in the logit of obesity prevalence between years – i.e., the velocity – from 1990 onwards (see Figure S5.1) indicates that an overall decline was observed for all countries. This finding indicates that the increase in obesity prevalence is slowing down.

![Figure 5.1. Age-standardized obesity prevalence (%) (20-84 yrs.) in 18 European countries and the US, 1975-2016, by sex.](image)

In Figure 5.2, the estimated age-standardized obesity prevalence from 1975-2016 and the projected obesity prevalence levels, with the 95% projection intervals from 2017-2100, are presented by sex for the UK and the US. Projections for all countries are presented in the Supplementary Material (Figure S5.2). These figures clearly indicate that our methodology is able to forecast obesity prevalence far into the future, thereby implementing the wave pattern of the obesity epidemic.

In the UK, obesity is expected reach a maximum level of 36.9% in 2034 for men and in 2033 for women (Figure 5.2). In the US, obesity is expected to reach maximum levels in 2031, at 43.6% for men and 44.4% for women.
Figure 5.2. Estimated and projected age-standardized obesity prevalence (20-84 yrs.) and 95% projection intervals in the UK and the US, 1975-2100, by sex.

Together with Ireland (36%), the US and the UK are the countries in our study that are expected to reach the highest maximum levels (Table 5.1). The lowest maximum levels are for men in the Netherlands (28%) and for women in Denmark (24%). The year in which the various countries are expected to reach the maximum level ranges from 2030 in the Netherlands to 2052 in Switzerland for men; and from 2026 in the Netherlands to 2054 in Switzerland for women. Apart from the Netherlands, Norway, and Portugal, all other countries will reach their maximum levels after the US and the UK (Table 5.1).
According to our forecasting model, obesity will decline after these maximum levels have reached. Table 5.2 summarizes the projected age-standardized obesity prevalence levels, with the 95% projection intervals, for the year 2060. Among men, the prevalence levels range from 13.1% (the Netherlands) to 36.9% (Switzerland). Among women, the prevalence levels range from 13.3% (the Netherlands) to 29.1% (the US).

**Table 5.1.** Expected maximum levels of age-standardized obesity prevalence (20-84 yrs.) and the year these levels will be reached in the 18 European countries and the US, by sex.

<table>
<thead>
<tr>
<th>Country</th>
<th>Expected maximum obesity prevalence (%) and 95% projection intervals</th>
<th>Expected year that the maximum will be reached and 95% projection intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Men: 32.6 (30.4; 35.9) Women: 25.9 (24.6; 27.9)</td>
<td>Men: 2040 (2035; 2045) Women: 2037 (2033; 2043)</td>
</tr>
<tr>
<td>Belgium</td>
<td>Men: 33.1 (31.3; 35.7) Women: 27.1 (26.2; 28.6)</td>
<td>Men: 2040 (2036; 2045) Women: 2036 (2031; 2043)</td>
</tr>
<tr>
<td>Denmark</td>
<td>Men: 34.2 (32.4; 36.7) Women: 24.0 (23.1; 25.2)</td>
<td>Men: 2042 (2039; 2047) Women: 2041 (2037; 2045)</td>
</tr>
<tr>
<td>Finland</td>
<td>Men: 34.7 (32.4; 38.6) Women: 28.7 (27.4; 30.8)</td>
<td>Men: 2042 (2036; 2049) Women: 2037 (2032; 2045)</td>
</tr>
<tr>
<td>France</td>
<td>Men: 31.6 (30.1; 33.9) Women: 27.1 (26.3; 28.1)</td>
<td>Men: 2038 (2034; 2042) Women: 2034 (2030; 2038)</td>
</tr>
<tr>
<td>Germany</td>
<td>Men: 36.4 (34.3; 39.5) Women: 30.3 (29.1; 32.3)</td>
<td>Men: 2041 (2037; 2047) Women: 2039 (2035; 2045)</td>
</tr>
<tr>
<td>Greece</td>
<td>Men: 37.4 (36.1; 39.0) Women: 32.5 (32.0; 33.1)</td>
<td>Men: 2044 (2042; 2047) Women: 2036 (2034; 2039)</td>
</tr>
<tr>
<td>Iceland</td>
<td>Men: 34.1 (32.0; 37.3) Women: 24.1 (23.3; 25.5)</td>
<td>Men: 2039 (2035; 2045) Women: 2034 (2030; 2041)</td>
</tr>
<tr>
<td>Ireland</td>
<td>Men: 36.7 (34.7; 39.9) Women: 35.5 (33.9; 37.7)</td>
<td>Men: 2037 (2034; 2042) Women: 2035 (2032; 2039)</td>
</tr>
<tr>
<td>Italy</td>
<td>Men: 28.3 (27.1; 30.1) Women: 26.4 (25.7; 27.5)</td>
<td>Men: 2036 (2032; 2041) Women: 2034 (2030; 2039)</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>Men: 34.7 (33.3; 36.6) Women: 26.4 (25.8; 27.3)</td>
<td>Men: 2037 (2035; 2041) Women: 2033 (2031; 2037)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Men: 28.0 (27.1; 29.0) Women: 25.6 (25.2; 26.0)</td>
<td>Men: 2030 (2028; 2032) Women: 2026 (2024; 2028)</td>
</tr>
<tr>
<td>Norway</td>
<td>Men: 32.8 (30.8; 35.8) Women: 28.8 (27.8; 30.4)</td>
<td>Men: 2035 (2031; 2041) Women: 2031 (2028; 2037)</td>
</tr>
<tr>
<td>Portugal</td>
<td>Men: 29.4 (27.8; 31.8) Women: 27.9 (27.1; 29.0)</td>
<td>Men: 2034 (2031; 2039) Women: 2030 (2027; 2034)</td>
</tr>
<tr>
<td>Spain</td>
<td>Men: 35.2 (33.8; 37.0) Women: 30.2 (29.5; 31.3)</td>
<td>Men: 2041 (2037; 2044) Women: 2037 (2033; 2043)</td>
</tr>
<tr>
<td>Sweden</td>
<td>Men: 33.1 (31.1; 36.2) Women: 24.6 (23.5; 26.3)</td>
<td>Men: 2038 (2034; 2044) Women: 2036 (2032; 2042)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Men: 37.9 (35.4; 41.4) Women: 27.1 (25.3; 29.9)</td>
<td>Men: 2052 (2047; 2058) Women: 2054 (2047; 2062)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>Men: 36.9 (35.5; 38.8) Women: 36.9 (35.8; 38.5)</td>
<td>Men: 2034 (2032; 2038) Women: 2033 (2031; 2037)</td>
</tr>
<tr>
<td>United States</td>
<td>Men: 43.6 (41.7; 46.7) Women: 44.4 (42.8; 46.9)</td>
<td>Men: 2031 (2028;2037) Women: 2031 (2027; 2036)</td>
</tr>
</tbody>
</table>

Our projected age-specific obesity prevalence levels (Supplementary Material, Figure S5.5) display an age pattern similar to the pattern observed in the past, with an inverse U-shape peaking around ages 60-69.
Table 5.2. Projected age-standardized obesity prevalence (%) (20-84 yrs.) and corresponding projection intervals in 2060 in the 18 European countries and the US, by sex.

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>25.7 (21.8; 31.6)</td>
<td>20.5 (18.0; 24.2)</td>
</tr>
<tr>
<td>Belgium</td>
<td>27.2 (24.0; 31.8)</td>
<td>23.2 (21.2; 26.2)</td>
</tr>
<tr>
<td>Denmark</td>
<td>29.3 (26.2; 33.4)</td>
<td>21.1 (19.4; 23.3)</td>
</tr>
<tr>
<td>Finland</td>
<td>29.9 (25.3; 36.4)</td>
<td>24.3 (21.4; 28.5)</td>
</tr>
<tr>
<td>France</td>
<td>24.3 (21.3; 28.4)</td>
<td>21.3 (19.6; 23.6)</td>
</tr>
<tr>
<td>Germany</td>
<td>31.0 (27.1; 36.2)</td>
<td>26.1 (23.7; 29.5)</td>
</tr>
<tr>
<td>Greece</td>
<td>33.2 (31.0; 35.9)</td>
<td>28.2 (27.0; 29.5)</td>
</tr>
<tr>
<td>Iceland</td>
<td>27.2 (23.3; 32.9)</td>
<td>19.5 (17.6; 22.4)</td>
</tr>
<tr>
<td>Ireland</td>
<td>26.5 (22.6; 32.2)</td>
<td>24.2 (21.2; 28.5)</td>
</tr>
<tr>
<td>Italy</td>
<td>21.1 (18.6; 24.6)</td>
<td>21.4 (19.7; 23.8)</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>26.0 (23.3; 29.6)</td>
<td>19.7 (18.3; 21.7)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>13.1 (11.8; 15.0)</td>
<td>13.3 (12.5; 14.4)</td>
</tr>
<tr>
<td>Norway</td>
<td>22.0 (18.2; 27.8)</td>
<td>19.8 (17.5; 23.3)</td>
</tr>
<tr>
<td>Portugal</td>
<td>17.9 (14.9; 22.4)</td>
<td>17.6 (15.8; 20.3)</td>
</tr>
<tr>
<td>Spain</td>
<td>30.0 (27.4; 33.3)</td>
<td>26.9 (25.2; 29.2)</td>
</tr>
<tr>
<td>Sweden</td>
<td>25.2 (21.5; 30.7)</td>
<td>19.7 (17.6; 22.9)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>36.9 (33.5; 41.2)</td>
<td>26.8 (24.3; 29.9)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>24.1 (21.5; 27.7)</td>
<td>25.7 (23.4; 28.8)</td>
</tr>
<tr>
<td>United States</td>
<td>26.8 (22.6; 33.7)</td>
<td>29.1 (25.4; 35.0)</td>
</tr>
</tbody>
</table>

5.4. Discussion

5.4.1. Summary of results

In 2016, the age-standardized obesity prevalence ranged from 19.5% (Swiss women) to 39.5% (US women). Over the 1990-2016 period, the increases in obesity prevalence declined. Obesity is expected to reach maximum levels from 2030 to 2052 among men and from 2026 to 2054 among women. These levels should be reached first in the Netherlands, the US, and the UK; and last in Switzerland. The maximum levels are expected to be highest in the US (44%) and the UK (37%), and lowest in the Netherlands (28% among men) and in Denmark (24% among women). In 2060, obesity is projected to range from 13.1% (Dutch men) to 36.9% (Swiss men). As in the past, the projected age-specific obesity prevalence levels have an inverse U-shape peaking around ages 60-69.

5.4.2. Discussion of the results

A direct comparison of our obesity prevalence projections with previous projections is hampered by the use of different forecasting methodologies, data, and age groups. Overall, however, these previous projections only provided short-term forecasts, and none of them
accounted for the wave pattern of the obesity epidemic. In general, the previous forecasts that used linear extrapolation only tended to project higher obesity levels than we did (McPherson et al., 2007; Ruhm, 2007; Wang et al., 2008); whereas the forecasts that took into account the recent observed levelling off in obesity (i.e., (Majer et al., 2013; Thomas et al., 2014) were closer to our findings, at least for the short term.

The wave pattern we predict follows the theoretical framework of Xu and Lam (2018), which is based on the hypothesis that the obesity epidemic will follow the wave pattern of the tobacco epidemic, as described by Lopez (1994). Xu and Lam also hypothesized more specifically that a maximum will be reached about 30 years after obesity prevalence is at 30%. If we applied this hypothesis to our data, obesity would be expected to reach maximum levels between 2017 and 2044 in our studied countries (see Table 5.2). This timing is largely in line with our projections, although not for each and every individual country. In addition, our projection that the highest maximum level will be around 44% in the US is quite distant from the theoretical generic maximum obesity level of 60% that Xu & Lam (2018) postulated. These differences in the timing and the maximum levels found can be attributed to differences in the approaches used: while Xu & Lam proposed a theoretical framework for application worldwide, our approach implemented the wave pattern empirically for 18 European countries and the US. As such our paper adds a strong empirical argument, to the theoretical one, obtained from 19 countries. Moreover, by focusing on Europe and the US, our empirical application was able to capture important cross-country variations in the levels and the timing of the maximum obesity prevalence, and thus highlights the differences between countries in the timing and the impact of the obesity epidemic.

Indeed, using our novel projection methodology, the maximum obesity prevalence is expected to range from 44% (the US) and 37% (the UK) to 24% (Danish women) and 27% (the Netherlands). We project that this maximum level will be reached between 2026 (Dutch women) and 2054 (Swiss women), with the US and the UK also reaching this level early.

Our expectation that the US and the UK will hold forerunner positions in terms of both timing and levels is in line not only with a previous forecast that focused on a few European countries as well as the US (Schneider et al., 2010), but with their current forerunner positions and with the previous literature. As highlighted in the results section, the US and the UK are currently the countries with the highest obesity prevalence levels. Previous studies have also shown
that the UK is the forerunner in obesity in Europe, not only because of its high obesity levels, but because its increases in obesity prevalence have been larger over time than elsewhere in Europe (Abarca-Gómez et al., 2017; Lifestyles statistics team, Health and Social Care Information Centre, 2014; NCD Risk Factor Collaboration, 2016). This increasing trend in obesity in the UK has been similar to the trend observed in the US, although the UK started from a lower level (Cutler et al., 2003). Earlier work also identified similarities in the obesity progression in the UK and the US (Vidra et al. (unpublished work); Vidra et al., 2018). The obesity levels in the UK and the US are fairly similar (Finucane et al., 2011), and the two countries share cultural characteristics that might predispose their populations to having similar eating and physical activity habits (Bambra, 2007; Soskice & Hall, 2001). However, compared to the US, the UK is expected to reach lower maximum levels a couple of years later; in line with the current differences in levels and timing. It should be noted that the UK differs from the US in terms of its socioeconomic conditions, food policies, and access to food technology (Cutler et al., 2003); and that these could be the factors that explain this observed gap. All in all, however, the trends in the UK are following those in the US rather closely, while the trends in the other European countries – led by Ireland - are following. The variations in the timing and the levels of the maximum obesity prevalence that we project for the remaining European countries can largely be explained by their current obesity prevalence rankings. The current differences between countries also reflect the timing of the obesity epidemic, and are related to differences in cultural, socioeconomic, nutritional and environmental factors (Abarca-Gómez et al., 2017; Blundell et al., 2017). Thus, according to our forecast, the countries with the lowest observed obesity levels in 2016 – namely, the Netherlands, Italy, and Portugal among men and Denmark and Sweden among women – are projected to reach relatively low maximum levels as well. Similarly, the countries with the highest observed current levels among both sexes, like Greece, Germany, and Ireland, are projected to reach higher levels than the other countries. These observations are in line not only with our expectations, but with a recent study forecasting obesity up to 2025 in the WHO European countries (Pineda et al., 2018).

However, our forecast does not project that all countries will keep the exactly same obesity prevalence ranking in the future that they held in the past. Among men, countries like Switzerland, Norway, and Iceland, which are ranked low or intermediate based on the latest
available obesity data, are forecasted to be at intermediate or high levels in the future. Among women, countries like Iceland and Luxembourg, which are currently ranked low to intermediate, are forecasted to reach very low or intermediate levels in the future. This change in country rankings can be largely explained by the country differences in the deceleration in obesity increases observed in the data after 2000 (see Figure S5.1). For instance, given the observed weak deceleration in obesity increases from 2000 onwards among Swiss men, Switzerland is projected to reach its maximum obesity prevalence levels relatively late. Thus, Switzerland is expected to cross over in the rankings with countries that are expected to reach their maximum levels sooner because of a stronger deceleration. It is important for policy-makers to keep this change in country rankings in mind.

5.4.3. Evaluation of data and methods

In selecting our data, we opted for the longest available validated time series of obesity prevalence data that were suitable for our forecast (Abarca-Gómez et al., 2017), and that had been used previously to study long-term time trends in obesity (Duncan & Toledo, 2018).

An important element of our forecasting approach was its assumption of a steady (=constant) negative acceleration; i.e., a steady (=linear) decline in the speed of change over time (=velocity) (see section 5.2.3). Without applying this assumption, it would not be possible to detect the kind of wave pattern that characterizes epidemics like the smoking (Lopez et al., 1994) and the obesity epidemics (Xu & Lam, 2018). However, the past trends in the obesity data we used show an unsteady negative acceleration (see Figure S5.3). Importantly, this is contrary to what we observed when we applied our model to the NCD data for 2016 (NCD Risk Factor Collaboration, 2016) and the data of Ng M 2014 (Ng et al., 2014). In these we observed on average a steady negative acceleration, at least from 1995 onwards (see Figure S5.3). This implies that the decline of the velocity will be steady and our result robust against using the data from NCDRisk (2016) and Ng et al. (2014).

We decided to employ age-period modelling instead of age-period-cohort modelling, despite the importance of the cohort dimension in obesity trends (Diouf et al., 2010; Faeh & Bopp, 2010; Robinson et al., 2013) and obesity-attributable mortality (Vidra et al., 2018). Our main reason for choosing this approach was the obesity data we used. Although these data were the most recent available comparable data, they were estimated using a Bayesian hierarchical model (see Abarca-Gómez et al., 2017) that included the age and the period dimensions, but
not the cohort dimension. Consequently, using an age-period-cohort model would result in unlikely cohort patterns that are exactly the same for the different countries. The inclusion of the cohort dimension would be an important step forward, and can be easily implemented in our approach by changing the underlying model into an age-period-cohort model, and by appropriately projecting the cohort parameters (one for each population).

Because of the unsteady negative acceleration patterns we observed, our choice to project the period parameter using data from 2000 onwards may have affected the outcomes of our forecast (Janssen & Kunst, 2007). See Supplementary Material, Table S5.3 and S5.4 where the results (maximum levels and years) when using different calibration periods are presented. Although the exact levels and years in which the maximum will be reached indeed vary, the same overall conclusion can be drawn that the US and the UK will keep their forerunner positions (particularly in terms of the levels for women and the timing for men); that the lowest maximum obesity prevalence levels will be reached in the Netherlands among men and in Denmark among women; and that Switzerland (except when using less than the 1995-2016 period) will reach the maximum level the latest.

As the current lower obesity limits, we used the country-, sex-, and age-specific prevalence levels of 40 years previously (in 1975) (Abarca-Gómez et al., 2017). Our main reasons for doing so were that it is unlikely that obesity prevalence will reach zero in the future; and that it is indeed very likely that the levels 35 years from now (in 2050) will be higher than the levels 40 years earlier, given that the wave pattern of the obesity epidemic is symmetric, and the peak of the epidemic lies somewhere in the future. The lower limit is, according to our projection model, of importance for the estimation of the acceleration, and, consequently, for the level and the year the peak. For instance, very high lower limits will result in higher maximum obesity levels in later years. It turned out that the age-standardized limits we chose (see Figure S5.19) were, on average, 10%, same as the proposed 10% level obesity is expected to reach at the final stage (Xu & Lam, 2018).

Our projection approach assumes that the obesity epidemic will follow the general wave pattern of epidemics, based on the recent theoretical framework of Xu & Lam 2018 (Xu & Lam, 2018). It should be noted, however, that the underlying epidemic wave pattern is debated by some scholars. These scholars have argued that the data have been misinterpreted due to bias, and that any stagnation is temporary, and will be followed by further increases (Visscher
et al., 2015). Our observation of a deceleration in the obesity increase over the period 1990 to 2016 however provides a strong empirical argument obtained from 19 countries in line with the theoretical argument. For the observed deceleration of the obesity increase to also turn into a plateau and an eventual decline, this will depend on whether indeed the time trends of the first and second derivatives of the obesity prevalence rates will continue in the same way as before. Continued attention to this issue and strong and effective public health policy is therefore warranted.

5.4.4. Conclusions and implications

Using our novel approach to project obesity prevalence into the long-term future, we expect obesity to reach maximum levels between 2026 and 2054 in the 18 non-Eastern European countries in our study sample and the US. The US and the UK are expected to achieve the highest maximum levels (at 44% and 37%, respectively) relatively soon (2031-2034), followed by the other European countries, for which the lowest estimated maximum level is 24% among Danish women.

In our approach, we implemented the underlying wave pattern of the epidemic based on the recent theoretical framework by Xu & Lam the observation of a deceleration in the obesity increase over the period 1990 to 2016. Thus, we expect that a maximum obesity level will be reached in all countries, followed by a decline. Yet, for the current slowdown in the increase of obesity to continue and to turn into a decline, (continued) effective public health action is required.
References


Human Mortality Database. (2018). University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Retrieved from http://www.mortality.org


Supplementary Material Chapter 5

Table S5.1. Fit of the model to the data for 1975-2016 (ages 20-84) by means of deviance, in 18 European countries and the US, by sex.

<table>
<thead>
<tr>
<th></th>
<th>Lee-Carter</th>
<th>APC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td>Austria</td>
<td>0.0329</td>
<td>0.0097</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.0180</td>
<td>0.0032</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.0445</td>
<td>0.0013</td>
</tr>
<tr>
<td>Finland</td>
<td>0.0733</td>
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</tr>
<tr>
<td>France</td>
<td>0.0332</td>
<td>0.0072</td>
</tr>
<tr>
<td>Germany</td>
<td>0.0395</td>
<td>0.0284</td>
</tr>
<tr>
<td>Greece</td>
<td>0.0512</td>
<td>0.0109</td>
</tr>
<tr>
<td>Iceland</td>
<td>0.0477</td>
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</tr>
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<td>0.0643</td>
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</tr>
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</tr>
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<td>Luxembourg</td>
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</tr>
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</tr>
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</tr>
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</tr>
<tr>
<td>United States</td>
<td>0.0372</td>
<td>0.0023</td>
</tr>
</tbody>
</table>

Because of the non-linearity of the model, $R^2$ could not be applied.

Comparison of the deviance of the APC and LC models shows that the latter fits the data better (lower values).
Figure S5.1. Velocity of the (transformed) logit of the obesity prevalence (20-84 yrs.) by means of the $f_t$ parameter, in 18 European countries and the US, 1990-2016, by sex.
Figure S5.2. Estimated and projected age-standardized obesity prevalence (ages 20-84) and 95% projection intervals in the 18 European countries and the US, 1975-2100, by sex.
**Table S5.2.** Estimated year at which the maximum obesity level will be reached in the 18 European countries and US (20-84yrs.) when the Xu & Lam hypothesis (Xu & Lam, 2018) is applied to our data, by sex.

<table>
<thead>
<tr>
<th>Year</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>2039</td>
<td>2043</td>
</tr>
<tr>
<td>Belgium</td>
<td>2034</td>
<td>2028</td>
</tr>
<tr>
<td>Denmark</td>
<td>2038</td>
<td>NA</td>
</tr>
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<td>Finland</td>
<td>2034</td>
<td>2031</td>
</tr>
<tr>
<td>France</td>
<td>2038</td>
<td>2033</td>
</tr>
<tr>
<td>Germany</td>
<td>2033</td>
<td>2031</td>
</tr>
<tr>
<td>Greece</td>
<td>2035</td>
<td>2018</td>
</tr>
<tr>
<td>Iceland</td>
<td>2035</td>
<td>2040</td>
</tr>
<tr>
<td>Ireland</td>
<td>2035</td>
<td>2033</td>
</tr>
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NA: In these countries, a maximum could not be estimated based on the current data, as for this maximum to be estimated, obesity prevalence must first reach 20%, which was not the case in these countries.
Figure S5.3. Acceleration of the (transformed) logit of the obesity prevalence (20-84yrs.) by means of the $f_t$ parameter, in 18 European countries and the US, 1975-2016, by sex for three different data sources: the data we used (NCDRisC 2017), and two other sources (NCDRisC 2016 and Ng et al. 2014).
Table S5.3. Expected maximum levels of age-standardized obesity prevalence (%) (20-84 yrs.) in the 18 European countries and the US, using different calibration periods (1995-2016, 2000-2016, 2005-2016, 2007-2016), by sex.

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For our forecast, we used the calibration period 2000-2016.
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**Table S5.4.** Year that the maximum age-standardized obesity is expected to be reached using different calibration periods.

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Figure S5.4. Age-standardized obesity prevalence (%) (20-84 yrs.) in 18 European countries and the US, by sex.

The dashed lines are the average age-standardized obesity prevalence across countries for both sexes (black), men (green) and women (orange).
Figure S5.5 Estimated and projected age-specific obesity prevalence (ages 20-84) in the 18 European countries and the US, 1975-2100, by sex.
Discussion
6.1. Objective and research questions

The aim of this study is to provide new and detailed insights into how the burden of obesity affects mortality at the population level, and how obesity is likely to develop in the future in Europe. More specifically, this thesis examined the evolution of obesity-attributable mortality over time across European countries and its impact on all-cause mortality, and used the knowledge acquired from this investigation to predict future obesity. The research questions that guided this study were as follows:

1. What are the past levels of and trends in obesity-attributable mortality in Europe, both across calendar year and birth cohorts, and how do these levels and trends differ across European countries?

2. What are the effects of obesity on all-cause mortality levels and trends, and how do these effects differ between countries?

3. How is the obesity epidemic likely to evolve in the future?

Most previous studies on obesity-attributable mortality focused on the US, or had other limitations. For example, these studies generally did not apply the same methodology simultaneously, which would have allowed for comparisons across countries and over time; or they concentrated on a single point in time, and did not take into account the age, period, and cohort dimensions.

This thesis went one step further, and helped to close the gaps in our knowledge of obesity-attributable mortality by providing several novelties. It focused on obesity-attributable mortality and its effect on mortality at the population level in Europe using cross-country comparisons and taking a temporal approach, which includes the birth cohort dimension. Through the application of this approach, important and detailed knowledge about the health of populations—which was previously limited—was obtained. This knowledge can be used to estimate the magnitude of the problem, and to guide public health policies. Furthermore, by applying the study’s findings on past trends and cross-country variation in obesity-attributable mortality, as well as the idea that the obesity burden evolves as an epidemic, this thesis has built a solid basis for estimating the future evolution of obesity trends. In this study, demographic and epidemiological data and methods were combined, which allowed for the use of a multidisciplinary approach in achieving the aims of this thesis.
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6.2. Summary of the findings

There are various methodologies available for estimating obesity-attributable mortality, each of which result in different estimates, and can impede the construction of time series. Chapter 2 evaluated the impact different estimation methods can have on the levels of and the trends in obesity-attributable mortality in the Netherlands over the 1981-2013 period. Approaches that use either all-cause mortality data or cause-specific death data were considered. Ultimately, we applied three all-cause approaches (a partially adjusted approach, a weighted sum approach, and the two approaches combined) and one cause-of-death approach (comparative risk assessment; CRA), which we adjusted in order to purely capture obesity. We used data on relative risks (RRs) obtained from both worldwide and European studies. The application of these different approaches led to different estimates of obesity-attributable mortality fractions (OAMFs). The OAMFs obtained for 2013 ranged from 0.9%, an estimate that was derived using the weighted-sum method and worldwide RRs; to 1.5%, an estimate that was derived using the adjusted CRA approach and less recent RRs. All of the approaches applied found an increase in OAMFs over the study period, except for the adjusted CRA approach, which showed a decrease among women.

Chapter 3 evaluated the age, period, and birth cohort effects and patterns of obesity-attributable mortality in eight European countries: namely, the Czech Republic, Finland, France, Germany, Hungary, Italy, Poland, and the UK. The findings indicated that over the 1990-2012 study period, there was an increase in age-standardized obesity prevalence and in OAMFs in most of these countries, and a decline in age-standardized obesity-attributable mortality rates (OAMRs) in all of these countries; albeit with some variation across countries. The results also showed that increasing OAMFs can be accompanied by decreasing OAMRs when the total mortality rate is decreasing faster than the OAMR. The contribution of nonlinear birth cohort effects to obesity-attributable mortality trends was found to be significant ($p < 0.01$) in all of the populations studied, except among men and women in the Czech Republic and Finland, and among German women and Polish men. The largest contributions, of more than 25%, were observed among men and women in the UK and among French women. In the UK, an increase in mortality rate ratios (MRRs) was observed for each successive cohort born after 1950. The analysis of the cohort patterns for the rest of the populations with significant cohort effects – namely, German men; Polish women; and French,
Hungarian, and Italian men and women – indicated that the MRRs increased in the cohorts born in 1935-1960, and decreased in the cohorts born in later years.

Chapter 4 focused on the impact of obesity on life expectancy levels and trends over the 1975-2012 period for the United States and for 26 European national populations: namely, Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden, Switzerland, Ukraine, and the United Kingdom.

In these 26 European countries, the age-standardized obesity-attributable mortality fraction (OAMF) was, on average, 11% among men and 10% among women in 2012. The potential gain in life expectancy (PGLE) if obesity was eliminated in these European countries in 2012 ranged from 0.86 to 1.67 years among men, and from 0.66 to 1.54 years among women. In the US, the PGLE in 2012 was estimated at 1.74 years for men and at 1.44 years for women. Over the study period, the PGLE increased in all countries, albeit more among men than among women. However, a levelling off of the increase in the PGLE after 1995 was observed among women in Denmark, Switzerland, and in the Central and Eastern European (CEE) countries. Without obesity, the increase in life expectancy at birth between 1975 and 2012 would have been, on average, 0.78 years higher among men and 0.30 years higher among women.

Chapter 5 presented a forecast of future obesity prevalence in 18 European countries and the US using a novel forecasting approach that took into account the underlying wave pattern of the obesity epidemic. The following European countries were included in this study: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. In 2016, the age-standardized obesity prevalence ranged from 19.5% (Swiss women) to 39.5% (US women). Over the 1990-2016 period, the increases in obesity prevalence declined. Obesity is expected to reach maximum levels among men from 2030 to 2052, and among women from 2026 to 2054. These levels should be reached first in the Netherlands, the US, and the UK; and last in Switzerland. The maximum levels are expected to be highest in the US (44%) and the UK (37%) and lowest in the Netherlands (28% among men) and in Denmark (24% among women). In 2060, obesity is projected to range from 13.1% (Dutch men) to 36.9% (Swiss men).

Overall, the findings of this thesis showed that the mortality burden of obesity in Europe has been significant, especially in terms of obesity-attributable mortality. Both obesity-
attributable mortality and the effect of obesity on life expectancy has been increasing over time, with important cohort effects. The results also revealed that there have been important differences between European countries in the mortality burden of obesity and its development at the population level; and that the obesity epidemic in Europe is expected to reach its peak, at levels of at least 25%, between 2026 and 2054.

Specifically, the age-standardized OAMF in 26 European countries in 2012 was estimated at, on average, 11% among men and 10% among women. The impact of obesity on life expectancy in Europe in 2012, as measured by the potential gains in life expectancy (PGLE) if obesity were eliminated, was estimated at, on average, 1.22 years among men and 0.98 years among women. The overall trend in OAMFs was found to be increasing in most of these countries. Between 1975 and 2012, obesity was shown to be responsible for 10% of the average change in life expectancy at birth among men, and for 5% of the average change in life expectancy at birth among women across these European countries. The findings indicated that the CEE countries had more irregular OAMF and PGLE trends than the Western, Southern, and Northern countries. While differences in OAMFs and PGLE were also observed between men and women, no clear pattern could be discerned. In addition to age and period effects, cohort effects on obesity-attributable mortality were found to be significant, albeit with considerable variation and some exceptions. It has been projected that in the European countries studied, the obesity epidemic will reach its maximum levels between 2030 and 2052 among men and between 2026 and 2054 among women, with values ranging from 24% (Danish women) to 44% (US men and women). Important differences between countries were observed in the values and the timing of these maximum levels, which indicate that different countries are in different phases of the obesity epidemic.

6.3. Reflections on the main findings

6.3.1. The mortality burden of obesity

It appears that the growth in the mortality burden of obesity, as measured by OAMFs and PGLE, is in line with the overall observed increase in obesity across Europe.

Specifically, the average OAMFs across Europe were found to have increased significantly, from 4% among men and around 6% among women in 1975 to 11% among men and 10% among women in 2012. This increasing trend in OAMFs seems to mirror a similar trend in
obesity levels, whereby countries with greater obesity increases and/or higher obesity levels also tend to have higher OAMFs, and vice versa. Hence, the observed differences in OAMFs reflect the differences in obesity prevalence levels among European countries (Finucane et al., 2011; Ng et al., 2014; NCD Risk Factor Collaboration, 2016). In particular, we found that countries with high obesity prevalence levels, such as Germany, the UK (chapter 3), Belarus, Hungary, Ireland, Norway, Spain, Russia, and the US (chapter 4), have relatively high OAMFs; while countries with lower obesity prevalence levels, such as France, Italy (chapters 3 and 4), the Netherlands, and Denmark (chapter 4), have relatively low OAMFs. While obesity and OAMFs did not increase substantially over time in all of these countries, particularly in the Central and Eastern European countries; they also started from higher levels (see subsection 6.3.2). It is important to note that in each of the chapters, different obesity prevalence data were used. These data differences can explain some of the differences in the findings of the chapters.

The findings on the impact of obesity on life expectancy in 2012 in European countries, as estimated by the potential gains in life expectancy (PGLE), showed that if obesity were eliminated, men would gain 1.22 years and women would gain 0.98 years, on average. Like for the OAMF trends, the PGLE trends largely followed the obesity trends, whereby countries with greater obesity increases and/or higher obesity levels also had higher PGLE, and vice versa. It was, for example, shown that Belarus, Hungary, Ireland, Poland, Russia, Spain, the UK, and the US had relatively large PGLE; while countries with lower obesity prevalence, like Denmark, France, Italy, the Netherlands, and Sweden, had lower PGLE.

One way to evaluate the (relative) importance of obesity’s impact on life expectancy is to compare its effects with those of other lifestyle factors known to affect life expectancy, like smoking and alcohol. The impact of smoking on life expectancy, expressed in terms of PGLE, was 2.38 years for men and 1.00 years for women in Western Europe, and 3.82 years for men and 0.67 years for women in CEE. The potential gains in life expectancy if alcohol were eliminated were estimated at 0.90 years for men and 0.44 years for women in Western Europe, and at 2.15 years for men and 1.00 years for women in CEE (Trias-Llimós et al., 2017). Thus, it appears that the impact of obesity on life expectancy lies between that of smoking and alcohol, and can be considered significant.
In addition, we found that without obesity, the increase in $e_0$ between 1975 and 2012 would have been, on average, 0.78 years higher among men and 0.30 years higher among women. Thus, obesity accounted for approximately 10% of the average change in $e_0$ among men and 5% of the average change in $e_0$ among women over this period. The effects of obesity on life expectancy trends are already far from negligible, and are expected to increase further, based on the US figures (by 13% among men and 15% among women), and on indications that obesity prevalence has been following an upward trend in all European countries. Our study also estimated the contributions of different birth cohorts to obesity-attributable mortality trends, and found significant cohort effects. Specifically, we found that the birth cohorts at higher risk of obesity-attributable mortality were the cohorts of men and women born after 1950 in the UK; and the cohorts of German men; Polish women; and French, Hungarian, and Italian men and women born between 1935 and 1960. However, there are no previous studies on the contributions of different birth cohorts to obesity-attributable mortality in European countries that could be used to validate these findings.

These findings clearly show that the UK has a cohort pattern that is completely different from those of other European countries, which more closely resemble the cohort patterns observed in the US (Masters et al., 2013). On the other hand, the observed variations across European countries reflect the large differences between European countries that can be seen in all of our findings (see 6.3.2.)

### 6.3.2. Variations between European countries

Important variations in the mortality burden, as measured by OAMFs and PGLE, and in its development, were observed across European countries. These variations seem to be related to the different stages of the obesity epidemic reached in different European countries.

When looking at the timing and the progression of the obesity epidemic in European regions, we can see a clear distinction between Western, Southern, Northern Europe on the one hand, and Central and Eastern Europe on the other. Specifically, we found that the CEE countries have experienced higher obesity prevalence levels than the Western European countries since the 1970s and the early 1980s (Silventoinen et al., 2004; Malik et al., 2013). However, since the 1980s, the obesity epidemic has progressed at a faster and more constant pace in Western, Northern, and Southern European countries than in CEE countries, where the trends have been more irregular (Finucane et al., 2011). In line with our findings in Chapter 4, it has
been shown that in CEE, increases in obesity prevalence and in OAMFs stagnated in the 1980-2008 period, and this became more pronounced in the 1990s (Bray & Bouchard, 2003; Finucane et al., 2011). This pattern coincides with the dramatic economic and political changes that these countries underwent in that period (Bray & Bouchard, 2003; Silventoinen et al., 2004; Finucane et al., 2011), which resulted in poorer nutrition and decreased energy supplies (Silventoinen et al., 2004). These and other changes led to a stagnation in obesity. However, some CEE countries still have very high obesity prevalence, as they started from higher levels (Silventoinen et al., 2004; Malik et al., 2013).

The remaining variations in obesity levels across countries are attributable to a combination of individual and contextual factors, including differences in dietary and physical activity patterns, socioeconomic levels, and obesogenic environmental conditions (Blundell et al., 2017; Harvard School of Public Health, 2018a). There are many factors that contribute to cross-country differences in obesity levels, and an exhaustive documentation of these factors is beyond the scope of our study. However, highlighting some of them is essential.

For example, dietary patterns, which vary considerably across European countries, help to explain differences in obesity risk levels (Pomerleau et al., 2003; Naska et al., 2006; Birt et al., 2017). Numerous differences in food habits related to geography, culture, and tradition all contribute to the diversity of dietary patterns. For instance, fruits and vegetables are much more widely available in Southern Europe than in CEE (Pomerleau et al., 2003). Moreover, the supply of dairy products has also long differed across regions, although in recent years the availability of these products in Southern and Eastern Europe has been increasing to levels equivalent to those in Northern and Western Europe (Birt et al., 2017). By contrast, alcohol availability and consumption has long been higher in CEE than in the rest of Europe (Popova et al., 2007; Bobak et al., 2016). Many countries of the Mediterranean basin are increasingly drifting away from the traditional Mediterranean diet and are adopting a more Westernised diet (Panagiotakos et al., 2006; Kontogianni et al., 2008; da Silva et al., 2009), whereas Northern European countries seem to be moving towards adopting healthier eating habits (increasing consumption of fruit, vegetables, and fish; and reducing consumption of fat) (Birt et al., 2017). These differences were reflected in our findings, as countries like Spain and Greece ranked higher in obesity than Northern European countries like Sweden, Finland, and Denmark.
Physical activity patterns also vary considerably across Europe. Some Southern European countries, like Greece, Italy, and Portugal, and some CEE countries, like Hungary, Poland, Romania, and Bulgaria, have reported low levels of physical activity; whereas Nordic and Western countries have reported relatively high levels of physical activity (Ulijaszek & Koziel, 2007; Ríos et al., 2016). These differences were reflected in our findings.

Socioeconomic status (SES), which is interpreted here as an individual factor that mainly refers to a person’s income and education, has been shown to be significantly associated with obesity. SES can modify the risk of obesity through, for example, dietary habits, access to exercise facilities, physical activity levels, and health literacy levels (Malik et al., 2013; Marques et al., 2017). It has been shown that people with higher SES have a lower obesity risk because they have greater ability and capacity than people with lower SES to adopt healthy dietary and physical activity habits (Robertson et al., 2007). Thus, obesity rates tend to be higher among people with lower than with higher SES (Devaux & Sassi, 2011). In addition, the literature has shown that countries with higher income levels and lower levels of inequality tend to have lower obesity levels, especially among women (WHO, 2014). There is, for example, evidence that countries that have lower levels of inequality and more favourable socioeconomic conditions, like Denmark, Sweden, and the Netherlands (OECD, 2017), have lower obesity levels and mortality burdens than countries with higher levels of inequality and less favourable socioeconomic conditions, like the UK, Spain, and Greece (OECD, 2017).

The abovementioned differences are strongly related as well to contextual factors, and to the obesogenic environment in particular. Food prices and availability, food stores, infrastructure, environmental structures, type of neighbourhood (defined by residential density and SES) are among the factors that affect the risk of obesity (Powell et al., 2010). The relationship between the types of neighbourhood and the obesity risk of the population is mediated by individual factors, such as food availability and choice (e.g., fruit and vegetable consumption and fast food consumption) and levels of physical and sedentary activities (Blundell et al., 2017).

An important point that is worth mentioning here is that the UK seems to be the forerunner in obesity levels in Europe. It has, for example, been shown that compared to other European countries, the UK has OAMF and PGLE levels that are higher, and that have increased more over time. These findings seem to be related to evidence that the UK has higher obesity levels and larger increases in obesity prevalence over time than elsewhere in Europe (Lifestyles
statistics team, Health and Social Care Information Centre, 2014; NCD Risk Factor Collaboration, 2016; Abarca-Gómez et al., 2017). There is, for example, research indicating that the increase in obesity in the UK has been similar to the increase observed in the United States, although the UK started from a lower level (Cutler et al., 2003); and that the obesity levels in the two countries are fairly similar (Finucane et al., 2011). The US and the UK have among the highest rates of obesity and of morbid obesity in the world. Possibly because these countries share cultural characteristics and a “liberal” economic system (Soskice & Hall, 2001; Bambra, 2007), it appears that in terms of the obesity epidemic, the UK is following the US rather closely, while the other European countries are following.

**6.3.3. The obesity epidemic in the future**

Our forecast suggests that obesity prevalence will further increase in the non-CEE countries studied, reaching a maximum level ranging from around 24% to 45% between 2026 and 2054, and will subsequently decline.

These results are in line with the theoretical framework by Xu and Lam, who argued that once a maximum level of obesity prevalence is reached in a country, it will be followed by a decline (Xu & Lam, 2018). However, as their estimates of when this maximum will be reached are based on theoretical considerations, they differ from our estimates.

Our results diverge from those of previous forecasts of obesity prevalence (i.e., (McPherson et al., 2007; Ruhm, 2007; Finkelstein et al., 2012; Majer et al., 2013; Thomas et al., 2014), as they did not forecast the long-term future, and they did not include in their approach a reversal from an increasing to a decreasing trend. In general, those previous forecasts that merely used linear extrapolation tended to project higher obesity levels (Ruhm, 2007; Wang et al., 2008; Pineda et al., 2018), whereas those forecasts that took into account the recently observed levelling off of obesity levels (Majer et al., 2013; Thomas et al., 2014) were more closely aligned to our short-term findings.

Partly in line with the observed variations in obesity prevalence and obesity-attributable mortality between countries, we also identified cross-country differences in the timing and the level of the expected peak in the obesity epidemic. Our findings indicated that the US is expected to reach the highest maximum level, followed by countries that had very high obesity levels for both sexes based on the last year of available data, like the UK, Ireland,
Greece, Germany, and Spain. The countries that are projected to reach the lowest maximum levels of obesity for both sexes are the Netherlands, Italy, and Portugal, which also ranked low on obesity levels based on the last year of available data. These findings are in line with the results of a recent study that forecasted obesity for 2025 in the WHO European countries, although the levels they projected are different from ours (Pineda et al., 2018). Not all countries are expected to retain their current obesity rankings in the future, however. For example, men in countries like Switzerland, Norway, and Iceland, which had low or intermediate obesity rankings based on the latest available obesity data, are forecasted to reach intermediate or high maximum levels in the future. Meanwhile, women in countries like Iceland and Luxembourg, which had low to intermediate obesity rankings, are forecasted to reach very low or intermediate maximum obesity levels in the future. These patterns are partly attributable to the data and to the observed variation in the deceleration of the obesity increase in all countries.

We found that the UK is closely following the US in terms of obesity levels and these countries will reach the maximum levels early. This result is in line with our other findings (6.3.1 and 6.3.2) and with the findings of the previous literature, which detected some similarities in the obesity progression patterns in the UK and the US; as we mentioned in 6.3.2. In addition, it is in line with a previous forecast that focused on a few European countries as well as the US (Schneider et al., 2010), and with their current forerunner positions. It therefore appears that the UK is currently the obesity forerunner among the European countries, and will have some of the highest obesity levels in the future. Consequently, it seems logical to assume that other European countries, especially non-CEE countries that are similar to the UK, will follow the UK’s example.

In summary, according to our forecast, which implements the underlying wave pattern of the epidemic, obesity will increase in all European countries, reach a maximum level, and then decline; although the timing and the values of these maximum obesity levels are expected to vary. However, reaching a maximum level that is followed by a decline will not occur naturally, and requires public health action (see 6.6).
6.4. Reflections on the methodological approach

6.4.1 Strengths of the approach and the innovativeness of the study

This study, which provided new and detailed knowledge about the mortality burden of obesity at the population level in Europe and the future evolution of the obesity epidemic, has several strengths.

The population-level approach we adopted was essential for obtaining important knowledge about how individual health risks are translated and accumulated in a population, thereby shaping its health; The population-level approach also provided us with detailed insights into the extent to which obesity is affecting mortality across Europe, which can be used to guide societies and public health policies (see section 6.6).

The cross-country comparison was essential for describing and highlighting the differences across countries, which did not receive much attention in previous studies. In addition, by applying the same estimation method across countries, we were able to ensure that the systematic bias remained the same, rendering our comparisons more robust. Furthermore, the use of a comparative framework offered insights into how different contextual and individual factors, along with cohort behavioural histories, modify the impact of detrimental factors like obesity (Mehta et al., 2017).

This thesis also used a temporal approach to gain important information on how obesity and obesity-attributable mortality evolved over time. We were able to explore in detail how obesity-attributable mortality affected life expectancy in the past, and up to the present. Previous studies that employed a temporal approach either focused on the US rather than Europe; or they provided information for specific time intervals only, while focusing little on the future trends in Europe. This study went two steps further by assessing past trends through an analysis of age, period, and cohort effects, and by projecting future obesity levels.

By including the birth cohort dimension, this PhD thesis has accounted for the complexity of the obesity epidemic, which is affected not only by age and calendar time (period), but by birth cohort (Reither et al., 2009). While there are no previous assessments of the contributions of birth cohorts to obesity in a European context, this dimension is believed to be key to understanding complex health issues (Masters et al., 2013). Our analysis revealed that cohorts contributed to past trends in obesity-attributable mortality, identified the
cohort effects reflect events that happen early in the life course that have long-lasting effects, they highlight the importance of interventions early in life. These findings can be used to guide the formulation of public health policies targeted at cohorts at elevated risk (see section 6.6).

This thesis took a novel approach to projecting future obesity trends, as the idea of the epidemic nature of obesity was implemented in the forecasting methodology. Our results provide information on the different phases of the obesity epidemic that have so far been reached in a large number of European countries, as well as long-term projections of obesity trends in these countries. By contrast, previous forecasts focused mainly on the US, or provided short-term forecasts only for a limited number of European countries.

Whereas most previous studies on this topic applied either a cross-country or a temporal approach, we combined these two approaches in this thesis. Through the use of this innovative methodology, we were able to provide more detailed insights into the mortality burden of obesity across Europe, and how it evolved over time. We also adopted a novel approach to projecting the future evolution of obesity.

6.4.2. Limitations of the study

The methods applied in this thesis, such as APC analysis, the PGLE estimation and forecasting approach, have their strengths and limitations, which are presented in detail in the relevant chapters (see chapters 2-5). Overall, however, the most important limitations of this study are related to the availability of data.

First, the findings of analyses based on a population-level approach should be interpreted with care, as they represent an average of aggregated results, and thus cannot be used to draw individual-level conclusions (Kindig et al., 2002). For instance, estimates of potential gains in life expectancy should not be interpreted as the years of life any individual would gain if obesity were eliminated; rather, these estimates represent an average of aggregated results.

Second, it is important to be aware of the limitations of the majority of the data we used in this study: namely, obesity prevalence data, RRs, and cause-specific mortality data. In the European context, longitudinal or follow-up cross-sectional health surveys that provide data on health indicators like obesity, and that are, ideally, linked to mortality data, are generally
missing. There are, of course, health surveys that have been conducted in several countries and that cover long periods of time, but the data from these surveys are not easily available. Moreover, these data are not always comparable across countries, as they are based on different methodologies (for instance, the Dutch health survey and the Health Survey for England).

As this thesis was developing, some comparative obesity data sources became available (Ng et al., 2014; NCD Risk Factor Collaboration, 2016; Abarca-Gómez et al., 2017), which enabled us to study long-term trends and make cross-country comparisons. These data stem from both the GBD/IHME and the NCD-RisC initiatives (Ng et al., 2014; NCD Risk Factor Collaboration, 2016; Abarca-Gómez et al., 2017), with the data from the NCD-RisC initiatives being updates of each other. These datasets are very different, and after carefully evaluating them, we discovered that they could not be used for all types of analysis. For instance, because the data from the NCD Risk Factor Collaboration (Ng et al., 2014; NCD Risk Factor Collaboration, 2016) were not suitable for capturing cohort patterns, we could not use them to apply age-period-cohort analysis. The obesity prevalence data (Ng et al., 2014; NCD Risk Factor Collaboration, 2016; Abarca-Gómez et al., 2017) used in this thesis consist of the available data based on measurements, supplemented with estimates when no data were available for specific countries and years. While the obesity data are validated, the data for countries that had less data available, like the CEE countries, should be treated with some caution (Ng et al., 2014; NCD Risk Factor Collaboration, 2016). These obesity data might have had an impact in our results, but in a systematic way (systematic bias).

Data availability was also an issue for the RRs, as both age- and sex-specific data derived from European studies only are missing. This lack of data influenced the methods we chose to apply (see below). In addition, although the relative risks of mortality associated with obesity likely differ across European countries, because of data limitations, we had to use a common RR for all of the European countries studied. This restriction certainly had an impact in our results, although the exact direction of this effect is unknown, as no relevant information is available. However, when we compared the RRs from worldwide studies with the RRs from European studies, we found that the latter were 7.6% higher, while the respective OAMF estimate was 41% higher (see Chapter 2). These results provide us with an indication of the potential impact if the RRs indeed differed across countries.
A similar problem arose regarding the plausible changes in RRs over time. The literature for the US has demonstrated that RRs have been changing over time, but some studies found a decline (Flegal et al., 2005; Mehta & Chang, 2011; Yu, 2012), while others found an increase (Yu, 2016). However, as there is no existing research that has investigated these issues in Europe, we were limited to using the time-constant RRs. This choice might have had an impact in our estimates of the time trend, although we used recent RRs to ensure that the current levels were estimated as precisely as possible. When keeping the RRs constant, it is impossible to take into account the changes that are happening over time, such as improvements in medical care, and especially advances in the treatment of cardiovascular disease, which may have influenced the relationship between obesity and total mortality. Moreover, when keeping the RRs constant over time, causes not related to obesity, such as fluctuations in all-cause mortality due to improved medical care or lower rates of smoking, can have an influence on the resulting OAMFs.

The third limitation of this PhD thesis was that the abovementioned data availability issues limited our ability to use advanced techniques (e.g., the cause-of-death approach and more advanced methods within the all-cause approach) to estimate obesity-attributable mortality. In order to apply cause-specific approaches, we need to have very detailed data on both BMI distribution and causes of death. For a study that covers a large number of European countries over a longer period of time, too little data of this kind are readily available. Among the all-cause approaches, we were limited to using only the methods allowed by our data; namely, the partially adjusted approach, the weighted sum approach, and the two approaches combined. If, however, obesity prevalence data of the decedents, mortality data linked with obesity data, and unadjusted RRs had been readily available, we would have been able to apply more advanced estimation methods as well (Flegal et al., 2015). The use of such methods would have inevitably had an impact on the outcomes, as our evaluation study in Chapter 2 showed.

6.5. Recommendations for future research

This thesis provided detailed insights into the impact of obesity on mortality in European countries. At the same time, it shed light on gaps in our current knowledge, and thus on areas of potential interest for future research. An important question that arises in studies of the burden of obesity is how estimates of obesity-attributable mortality can be improved. There
are three main research directions that could address this issue: namely, a) the collection of comparable obesity prevalence data; b) the collection of more specific RR data (country- and time-specific data); and c) the use of indexes other than BMI to capture obesity. Such innovations could provide better and more comparable estimates of obesity-attributable mortality, now and in the future.

a) **Comparable obesity prevalence data**

Obesity prevalence data that both cover a long period of time and are comparable across countries were not available when this PhD thesis was started. The subsequent publication of comparative obesity data sources (BMI ≥30kg/m²) that were based on the available data, and were supplemented with model estimates when the necessary data were not available (Ng et al., 2014; NCD Risk Factor Collaboration, 2016; Abarca-Gómez et al., 2017) (see 6.4.2 for further details), was very helpful for our purposes. Nevertheless, in the European context, longitudinal studies that provide measured obesity data that are comparable across countries would give researchers a great tool to use in future obesity studies. Conducting such studies would be especially helpful in the CEE countries, where the existing data are very scarce.

Specifically, the all-cause approaches would benefit from the inclusion of better data related to obesity prevalence in general and obesity prevalence among the decedents, and from the identification of the best index for defining obesity at the population level and RR data (see next subsection). The cause-specific approaches would benefit greatly from measured BMI distribution data, which currently are not readily available for European countries, especially for longer time periods.

Furthermore, future studies could provide important information on obesity indexes that use measures other than BMI, such as waist circumference, maximum weight in a lifetime, body weight trajectories, BMI distribution data (mean values and standard deviation) (see subsection: c) Exploration of indexes that could capture obesity better than BMI). These data are essential when applying more advanced estimation techniques for measuring obesity-attributable mortality, and may provide more accurate estimates.

b) **More specific RR data**

This thesis also showed that there are gaps in knowledge and data on RRs. In particular, we lack knowledge about the plausible changes in RRs over time, the extent to which RRs differ
according to the country-specific context, and the non-availability of data on RRs unadjusted for confounding. The existing studies on the plausible changes in RRs over time produced contradictory findings, and were focused exclusively on the US, as mentioned previously (see 6.4.2). Thus, studies are needed that can shed light on the question of whether there are plausible changes in RRs in Europe (Mehta & Chang, 2011); and that can give essential information on the changes, if any, in the relationship between obesity and all-cause mortality that are occurring because of improvements in medical care, the better management of cardiovascular disease, and the decline in cardiovascular mortality.

Moreover, there is no existing research on potential differences in RR values across European countries. Cohort studies that estimate in a comparable manner the RRs in European countries, which could be then used for cross-country comparisons, are needed to disentangle this question (Mehta et al., 2017). Furthermore, the lack of availability of RRs that are unadjusted for confounding was a limiting factor in the methods we were able to use to estimate obesity-attributable mortality (see 6.4.2 and Chapter 2). Thus, studies that provided more detailed information on RRs and on non-adjusted RRs data would improve our estimates of obesity-attributable mortality.

c) Exploration of indexes other than BMI to capture obesity

A Body Mass Index of ≥30kg/m² is the most widely used measure of obesity, mostly because it is convenient, as it only requires information on height and weight. Yet BMI has several limitations (National Research Council, 2011). One of the main criticisms of BMI is that it does not give any information on body fat and muscle composition, and it does not distinguish between central obesity or adiposity (i.e., increased fat accumulation surrounding the intra-abdominal organs) and peripheral adiposity (i.e., accumulation of excess fat in the buttocks, hips, and thighs), even though the former has been found to have a more negative effect than the latter (Oliveira, Andreia et al., 2010; Oliveira, A. F. et al., 2010; Zheng et al., 2013). In older adults, BMI use has several limitations due to the differential loss of muscle and lean body mass that accompanies ageing, and to illness-related weight loss (National Research Council, 2011). Thus, the normal weight range in older adults might be slightly higher; i.e. ≥23 kg/m² (Starr & Bales, 2015).

Previous research in the US looked at the use of other indexes, including BMI trajectories, maximum weight in the lifespan, waist circumference, and waist-to-hip ratio (Zheng et al.,
2013; Stokes, 2014; Howell et al., 2017). The results of these studies suggested that the association of these indexes with mortality is promising (Zheng et al., 2013; Stokes, 2014; Howell et al., 2017). Thus, future research in Europe could focus on replicating these findings, and on further exploring the question of the potential role of the duration of obesity on mortality risk (Abdullah et al., 2011).

With more comparable, detailed, and accurate data, the estimation of the mortality burden of obesity now and in the future can be further improved. For example, it would then become feasible to include the cohort dimension when projecting obesity prevalence, and, subsequently, obesity-attributable mortality.

6.6. General implications for society and recommendations for policy-makers

This PhD thesis showed that the mortality burden of obesity (OAMF, PGLE) at the population level is significant and is increasing over time, with important cohort effects. It also revealed that there are important variations in the mortality burden of obesity, and in the development of this burden, across European countries. Furthermore, this thesis showed that the obesity epidemic is projected to further increase, reaching a maximum level of at least 25% between 2026 and 2054 in European countries. These findings have important implications, as they indicate that obesity and its associated burden warrants further attention from both societies and public health policy-makers.

The outcomes of this thesis clearly show that the obesity epidemic is a serious challenge not just in the US, but in European societies, which are increasingly burdened by obesity. We argue that action should be taken to tackle the current and future obesity epidemic, since in addition to health effects, obesity has economic and social consequences (Harvard School of Public Health, 2018b), and thus affects societies in multiple ways. In terms of health effects, obese individuals face a higher risk of developing several comorbidities, as we mentioned previously (see 1.5, 1.6). Moreover, our findings suggest that obesity-attributable deaths and the effects of obesity on life expectancy are increasing over time. The health care costs associated with obesity are also thought to be considerable. For instance, in 2014, the economic impact of obesity was estimated to be 2.0 trillion US dollars globally, or 2.8% of the global gross domestic product (GDP) (Dobbs et al., 2016). In Europe, obesity has been shown to account for between 5% and 7% of health care costs (Finkelstein et al., 2005). Obesity has also been recently recognised as a source of stigma, which is in itself a significant cause of
health inequalities, and is associated with physiological and psychological consequences, such as increased depression and anxiety levels and decreased self-esteem (WHO, 2018).

As obesity constitutes a considerable burden for societies and a major public health concern, a wide range of obesity-related public health policies have been developed and implemented across the globe (i.e., World Health Organization, 2014; European Association for the Study of Obesity, 2017; Paxman & Parkhurst, 2018). Although these policies were not able to prevent or fully tackle the epidemic, some important lessons have been learned from the implementation of these measures that can guide the development of future policies.

First, this study found that obesity constitutes a significant burden, and that effective public health policies for limiting the spread of the obesity epidemic in Europe are warranted.

Second, improvements in knowledge about obesity are needed, especially in Europe. Specifically, future studies should give a comprehensive overview of the obesity epidemic and the obesity burden, providing temporal (including birth cohorts) and cross-country information on obesity trends, and exploring the underlying drivers. As this thesis has demonstrated, research that better describes the obesity burden can help to guide the design of effective policies.

Third, this thesis has shown that there are large variations in obesity and its associated burden across European countries and its regions, and especially between Central and Eastern Europe and the rest of Europe. It has been argued that key to formulating successful interventions and policies is the recognition of local factors and particularities. Thus, having an accurate, individualised picture of each country is essential for the development of “tailor-made” strategies for different countries (Cuschieri & Mamo, 2016). A further step is recognizing that a single approach, even if it is specific to a country, cannot be effective for all individuals and groups of people. Therefore, tailor-made strategies that address different groups of people should be used whenever possible to complement the specialized strategies for each individual country.

Fourth, the large variations observed across countries are related to individual and contextual factors that modify the risk of obesity. As obesity is a disease that is affected by many factors – and is thus a multifactorial disease – treating it requires multi-level interventions. As several working groups have recognised, it is essential that the factors that affect obesity at all levels
are addressed, including individual behavioural factors, social and physical conditions, and national and local policies (Stevens et al., 2017; Paxman & Parkhurst, 2018). In addition to recommending multi-level interventions, several working groups have noted the importance of multi-sector interventions, or actions between two or more sectors. Such interventions may, for example, include the government, health, agro-food, transport, and educational sectors, based on “a health in all policy” approach (Stevens et al., 2017; Paxman & Parkhurst, 2018). According to the WHO, a health in all policy is defined as “an approach on health-related rights and obligations. It improves accountability of policymakers for health impacts at all levels of policy-making”. Thus, this approach further highlights the need to focus on health.

Fifth, the contributions of birth cohort effects that were revealed in our thesis point to the importance of interventions starting early in life, which should encourage the development and maintenance of lifelong healthy eating and physical activity patterns (WHO, 1998). Such interventions are needed not only in countries with birth cohorts at increasing risk, but in all countries, as they represent effective preventive measures. Furthermore, these policies can complement period-focused policies, such as the taxation of sugary foods and drinks, improvements in the quality of the food provided at schools, and efforts to decrease the price of healthy foods. Such interventions have already been shown to be at least moderately effective (Paxman & Parkhurst, 2018).

It is important to note that we looked at the mortality burden of obesity only, even though the burden of obesity is not limited to mortality, as it affects societies in many different ways (morbidity, quality of life, economic burden, etc.). In light of our observations of current conditions and based on our projections, it appears likely that obesity will increase further in the future, and will become a significant public health problem in all countries, including in countries that currently have relatively low obesity prevalence levels. Although our forecast indicates that there will be a turning point in the epidemic in the future, it is important to keep in mind that such a shift will not happen naturally. Thus, public health action on obesity is more important than ever before.

The abovementioned policies are therefore essential, not only for tackling the obesity epidemic, but for improving the overall health and well-being of populations across Europe, today and in the future.
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**English Summary**

**The obesity epidemic in Europe: Assessing the past and current mortality burden and the future of obesity.**

Obesity is considered one of the biggest public health challenges of the 21st century, not only because of its epidemic nature, but also because of its serious health effects. As obesity is associated with a higher risk of developing a range of diseases, and, ultimately, of mortality, it represents a considerable threat to the health of populations. This threat is especially relevant in Europe, which has been hit hard by the obesity epidemic. Europe is currently the region with the second-highest obesity prevalence levels worldwide after the US. Given that large numbers of Europeans are suffering from obesity, gaining a deeper understanding of the future progression of obesity in Europe, and of its associated mortality burden, is essential.

Despite the importance of research on obesity, detailed knowledge of the mortality burden of obesity in Europe, and of how it is changing over time, is limited. Most previous research on the mortality burden of obesity focused on the USA, or on a single European country. Moreover, most of these studies focused on the mortality burden at a single point in time. As a result, we lack a comparative framework of the mortality burden of obesity in Europe, and of the time trends in the development of this burden.

The main objective of this thesis was to provide new and detailed insights into how obesity affects mortality levels and trends at the population level in Europe, and how the obesity epidemic in Europe is likely to develop in the future.

In this thesis, a multidisciplinary approach was applied that combined knowledge, methods, and data from both demography and epidemiology. For the analysis, recent demographic and epidemiological data were used, and advanced demographic and statistical modelling techniques were applied. By applying both a cross-country approach and a temporal approach (by focusing on past and future trends), detailed comparable information with considerable public health relevance was obtained.

Chapter 1 presented background information, and framed the problem and the research questions. It also described the recent state of the art in the following areas of obesity research: the mortality burden associated with obesity, especially in terms of obesity-attributable mortality; the impact of obesity on all-cause mortality/life expectancy; and the future burden of obesity.

Chapter 2 attempted to determine which methods for estimating obesity-attributable mortality can be applied in a European setting when taking a temporal approach. More specifically, the impact of these methods on the levels and trends in obesity-attributable mortality was evaluated for the
Netherlands over the 1981-2013 period. Three all-cause approaches (a partially adjusted approach, a weighted sum approach, and the two approaches combined) and one cause-of-death approach (comparative risk assessment (CRA), which we adjusted to purely capture obesity) were applied. The results showed that the application of these different approaches led to different estimates of obesity-attributable mortality fractions (OAMFs) in the Netherlands, ranging from 0.9% to 1.5% in 2013. All of the approaches revealed that there was an increase in OAMFs over the study period, with the exception of the adjusted CRA approach, which showed a decrease among women. Thus, estimates of obesity-attributable mortality levels and trends differed depending on the method applied.

Chapter 3 evaluated the contribution of age, period, and birth cohort effects and patterns in obesity-attributable mortality in eight European countries: namely, the Czech Republic, Finland, France, Germany, Hungary, Italy, Poland, and the UK. Obesity prevalence and all-cause mortality data by age (20-79), sex, and country for the 1990-2012 period were used in the analysis. The results indicated that the nonlinear birth cohort contributed significantly to obesity-attributable mortality trends \( (p < 0.01) \) in all of the populations studied, except among men and women in the Czech Republic and Finland, and among German women and Polish men. The largest contributions, which exceeded 25%, were observed among men and women in the UK and among women in France. Increases in mortality rate ratios (MRRs) for each successive cohort born after 1950 were found only among men and women in the UK. For the rest of the populations with significant cohort effects – namely, German men; Polish women; and French, Hungarian, and Italian men and women – the analysis showed that the MRRs increased in the cohorts born in 1935-1960, but decreased in the cohorts born thereafter. To conclude, the birth cohort dimension is important for describing and explaining trends in obesity-attributable mortality.

Chapter 4 aimed to assess the impact of obesity on life expectancy levels and trends over the 1975-2012 period for the United States and for 26 European national populations: namely, Austria, Belarus, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden, Switzerland, Ukraine, and the United Kingdom. This was done by measuring the potential gain in life expectancy (PGLE) if obesity-attributable mortality had not occurred. The results show that in the 26 European countries in 2012, the PGLE ranged from 0.86 to 1.67 years among men and from 0.66 to 1.54 years among women, and was estimated to be 1.74 years among men and 1.44 years among women in the US. The PGLE showed an increase in all of these countries over the study period, and was stronger among men than among women. However, the findings also indicated that the PGLE levelled off after 1995 among women in Denmark, Switzerland, and the Central and Eastern European (CEE) countries. When we estimated the increase in life expectancy at birth between 1975
and 2012 without obesity, we found that the increase would have been, on average, 0.78 years higher among men and 0.30 years higher among women. Thus, obesity has affected both life expectancy levels and life expectancy trends in Europe, albeit to varying degrees across countries and between women and men.

Chapter 5 aimed to forecast obesity over the long term using a novel approach that took into account the underlying epidemic wave pattern implemented in the Lee-Carter forecasting technique. The countries included in the forecast were Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Obesity prevalence data for 1975-2016 were used. The analysis of past trends showed that obesity increased in all of the countries between 1975-2016, but that the increase in obesity prevalence declined over the 1990-2016 period. Obesity was projected to reach maximum levels between 2026 and 2054, and these maximum levels were estimated to be highest in the US (44%) and the UK (37%) and lowest in the Netherlands (28% among men) and Denmark (24% among women). It was further projected that the highest maximum levels will be reached first in the US and the UK. Thus, the findings suggest that the obesity epidemic in Europe will reach its peak between 2026 and 2054 at levels of at least 25%.

Finally, in Chapter 6, the main results are summarized and discussed in detail. In addition, reflections on the methodological approach and the implications of the findings for public health policies are presented.

Overall, this PhD thesis revealed that the mortality burden of obesity in Europe is significant, albeit with clear variations between countries. Specifically, the obesity-attributable mortality fraction (OAMF) in the 26 European countries in 2012 was estimated at, on average, 11% among men and 10% among women. The impact of obesity on life expectancy in Europe in 2012, as measured by the potential gains in life expectancy (PGLE) if obesity was eliminated, was estimated at, on average, 1.22 years among men and 0.98 years among women. The mortality burden of obesity was found to be slightly lower, on average, in Western than in Eastern Europe. Within Western Europe, the UK exhibited the largest mortality burden. The mortality burden of obesity (OAMF, PGLE) was shown to increase over time, with essential birth cohort effects. According to our forecast, the obesity epidemic in Europe will reach its peak between 2026 and 2054 at levels of at least 25%.

The considerable mortality burden of obesity found for Europe is in line with the high obesity prevalence levels observed across Europe. Similarly, the finding that the mortality burden of obesity has increased over time is in line with the observation that obesity prevalence has increased sharply in Europe in recent decades. A comparison of the current PGLE estimates of obesity with those of
smoking and alcohol showed that the impact of obesity on life expectancy levels lies between that of smoking and alcohol. It is, therefore, clear that the mortality burden of obesity in Europe should not be ignored.

The variations in the mortality burden observed across European countries can be related to the different stages of the obesity epidemic these countries have reached. Specifically, the progression of the obesity epidemic has clearly differed in Western and in Eastern Europe, mainly because the economic and political changes that occurred in Eastern Europe only led to the stagnation of obesity in those countries. The remaining variations observed across countries have been attributed to a wide range of contextual and individual factors, such as differences in economic and political conditions, in obesogenic environments, and in dietary and physical activity patterns that are partly related to socioeconomic status.

Our findings clearly show that of the Western European countries studied, the UK is the forerunner in the obesity epidemic, and thus closely follows the trends observed in the US.

This thesis encompassed some novelties and went beyond previous research. Specifically, our use of a comparative framework in combination with a temporal approach provided us with detailed insights into the mortality burden of obesity and its development over time. For the first time in a study conducted in Europe that focuses on obesity-attributable mortality, the birth cohort dimension was included. In addition, we applied a novel projecting approach that enabled us to generate long-term forecasts. At the same time, this PhD research was subject to limitations, including limitations in the majority of the data used; namely, the obesity prevalence data, the relative risk data, and the cause-specific mortality data. Future research would greatly benefit from studies that address this knowledge gap, as the data produced by such studies could improve the estimates of obesity-attributable mortality.

The results of this thesis have important implications, as they indicate that obesity and its associated mortality burden should be given more attention in both societal and public health policy discussions. In particular, public health policies that are effective in preventing obesity from increasing further are needed. The large variations in obesity and its associated mortality burden that have been found across European countries suggest that strategies tailored to different countries, combined with multi-level interventions, are required to address the multifactorial aetiology of obesity. Our finding that birth cohort effects play a large role in obesity trends suggest that interventions starting early in life could contribute to the development and maintenance of healthy habits. These policies are essential not only for tackling the obesity epidemic, but for improving the overall health and well-being of populations across Europe, today and in the future.
Nederlandse samenvatting

De Europese obesitasepidemie: bepaling van de sterftelast in heden en verleden en de mogelijk toekomstige ontwikkeling

Obesitas wordt gezien als een van de grootste uitdagingen voor de volksgezondheid van de 21e eeuw, niet alleen vanwege het epidemische karakter ervan maar ook vanwege de ernstige gezondheidseffecten. Obesitas wordt geassocieerd met een hoger risico op een groot aantal aandoeningen en uiteindelijk op overlijden en vormt een ernstige bedreiging van de volksgezondheid. Dit is vooral belangrijk in Europa, een regio die zwaar getroffen is door de obesitasepidemie: na de VS heeft Europa de hoogste obesitasprevalentie ter wereld. Omdat veel Europeanen lijden aan obesitas is het essentieel een beter begrip te krijgen van de sterftelast die hiermee gepaard gaat en van de mogelijk toekomstige ontwikkeling van de obesitasepidemie in Europa.

Ondanks de relevantie van onderzoek naar obesitas is er weinig gedetailleerde kennis over de obesitasgerelateerde sterftelast in Europa en hoe deze in de tijd verandert. De meeste studies concentreerden zich op de VS of op een bepaald Europees land en op de sterftelast op een specifiek moment. Zodoende ontbreekt landenvergelijkend onderzoek naar de obesitasgerelateerde sterftelast in Europa en de ontwikkeling daarvan.

Het hoofddoel van dit proefschrift is het verkrijgen van nieuwe en gedetailleerde inzichten in de invloed van obesitas op sterfteniveaus en lange-termijn sterfteleontwikkelingen in Europa en hoe de Europese obesitasepidemie zich waarschijnlijk zal ontwikkelen.

Hiervoor is een multidisciplinaire aanpak gehanteerd, waarin kennis, methoden en data uit de demografie en de epidemiologie zijn gecombineerd. Voor de analyses worden recente demografische en epidemiologische data gebruikt en geavanceerde demografische en statistische technieken toegepast. Door zowel landenvergelijkend als dynamisch te werk te gaan (o.a. door ontwikkelingen in het verleden en de toekomst te onderzoeken) werd gedetailleerde vergelijkende informatie verkregen die van groot belang is voor de volksgezondheid.

Hoofdstuk 1 presenteert achtergrondinformatie, plaatst het probleem en de onderzoeksvragen in perspectief en bespreekt de stand van zaken op het gebied van onderzoek naar obesitas, naar obesitasgerelateerde sterftelast, naar het effect van obesitas op de algehele sterfte en de levensverwachting en naar de toekomstige ontwikkeling van obesitas.

Hoofdstuk 2 bespreekt welke methoden gebruikt kunnen worden om obesitasgerelateerde sterfte te schatten in de Europese situatie en diens ontwikkeling over tijd. Meer specifiek wordt het effect van deze methoden op de Nederlandse obesitasgerelateerde sterfte en de ontwikkeling daarvan.
onderzocht voor de periode 1981 tot 2013. Hierbij zijn drie methoden gebruikt gebaseerd op algehele sterfte data (de “partially-adjusted” methode, de “weighted-sum” methode, en een combinatie van beide) en een methode gebaseerd op doodsoorzaakspecifieke data (de “comparative risk assessment (CRA)” methode die we aanpasten om uitsluitend obesitas mee te nemen). De resultaten laten zien dat toepassing van de verschillende methoden tot schattingen van het aandeel van totale sterfte dat aan obesitas gerelateerd is (obesitasgerelateerde sterftepercentages) leiden die variëren van 0,9% tot 1,5% voor Nederland in 2013. Het merendeel van de methoden laten zien dat de obesitasgerelateerde sterftepercentages toenemen in de onderzochte periode; alleen de aangepaste CRA-methode geeft een afname onder vrouwen aan. Schattingen van de obesitasgerelateerde sterfte en ontwikkelingen hierin hangen dus af van de gehanteerde methode.


In hoofdstuk 4 wordt het effect van obesitas op de levensverwachting en de ontwikkeling ervan beoordeeld voor de periode 1975-2012 voor de Verenigde Staten en 26 Europese landen: België, Denemarken, Estland, Finland, Frankrijk, Hongarije, Ierland, Italië, IJsland, Letland, Litouwen, Luxemburg, Nederland, Noorwegen, Oekraïne, Oostenrijk, Polen, Portugal, de Russische Federatie, Slowakije, Spanje, Tsjechië, het Verenigd Koninkrijk, Wit-Rusland, Zweden en Zwitserland. Dit werd gedaan door de potentiële stijging van de levensverwachting (potential gain in life expectancy, PGLE) te berekenen als obesitas-gerelateerde sterfte buiten beschouwing wordt gelaten. De resultaten tonen aan dat voor de 26 Europese landen in 2012, de PGLE tussen 0,86 en 1,67 jaar is voor mannen en tussen 0,66 en 1,54 jaar voor vrouwen. In de VS werd de PGLE geschat op 1,74 jaar voor mannen en 1,44 jaar voor vrouwen. Tijdens de onderzochte periode nam de PGLE toe in alle landen (sterker voor mannen
dan voor vrouwen). Na 1995 wordt de toename van de PGLE minder groot voor vrouwen in Denemarken, Zwitserland en de Centraal- en Oost-Europese landen. Als we de toename van de levensverwachting bij de geboorte schatten voor een scenario waarin obesitas niet voorkomt tussen 1975 en 2012, is deze gemiddeld 0,78 jaar hoger voor mannen en 0,30 jaar hoger voor vrouwen. In Europa heeft obesitas dus invloed op zowel de huidige levensverwachting als de ontwikkeling van de levensverwachting, maar deze invloed verschilt per land en per geslacht.


Tot slot worden in **hoofdstuk 6** de belangrijkste resultaten samengevat en in detail besproken. Daarnaast geeft dit hoofdstuk een reflectie op de methodologische aanpak weer en presenteert het de consequenties van de resultaten voor het volksgezondheidsbeleid.

Samenvattend laat dit proefschrift zien dat de obesitasgerelateerde sterftelest in Europa substantieel is en dat er in dit opzicht duidelijke verschillen zijn tussen landen. Meer specifiek werd het obesitasgerelateerde sterftelestepercentage in de 26 onderzochte Europese landen in 2012 geschat op gemiddeld 11% voor mannen en 10% voor vrouwen. Als obesitas niet zou voorkomen, zou de levensverwachting in Europa in 2012 gemiddeld 1,22 jaar hoger zijn voor mannen en 0,98 jaar voor vrouwen. In West-Europa was de obesitasgerelateerde sterftelest gemiddeld iets lager dan in Oost-Europa, met het Verenigd Koninkrijk als koploper in West-Europa en dit cijfer het hoogst in het Verenigd Koninkrijk. De obesitasgerelateerde sterftelest nam toe tijdens de onderzochte periode, met hierin belangrijke verschillen tussen geboortegeneraties. Volgens onze voorspelling zal de Europese obesitasepidemie zijn hoogtepunt bereiken tussen 2026 en 2054, met een prevalentie van ten minste 25%.
De aanzienlijke obesitasgerelateerde sterftelelast in Europa strookt met de hoge prevalentie van obesitas onder Europeanen. De toename van deze sterftelelast sluit ook aan bij de toename van het aantal obesitaspatiënten in Europa in de laatste decennia. Als we de huidige schattingen van het effect van obesitas op de levensverwachting vergelijken met die voor roken en alcoholgebruik, dan ligt deze voor obesitas tussen die van roken en alcoholgebruik. Deze obesitasgerelateerde sterftelelast in Europa is dan ook te aanzienlijk om genegeerd te worden.

De waargenomen verschillen in sterftelelast tussen Europese landen kunnen verklaard worden door de verschillende stadia waarin de obesitasepidemie zich in deze landen bevindt. Meer specifiek is er een duidelijk verschil tussen West- en Oost-Europa in het voortschrijden van de obesitasepidemie, voornamelijk als gevolg van de economische en politieke veranderingen die zich alleen in de laatstgenoemde regio voordeden en de toename van obesitas een halt toeriepen. De overige verschillen tussen de landen lijken te maken te hebben met een groot aantal omgevings- en individuele factoren, zoals andere economische en politieke verschillen, verschillen in hoeverre de omgeving obesitas bevordert, en verschillen in individuele voedings- en bewegingspatronen die deels voortkomen uit verschillen in sociaaleconomische status.

Uit de resultaten blijkt duidelijk dat van de onderzochte West-Europese landen het Verenigd Koninkrijk vooroploopt waar het gaat om de obesitasepidemie en hierin de Verenigde Staten op de voet volgt.

Dit proefschrift bevat enkele nieuwe elementen en gaat verder dan het bestaande onderzoek. Meer specifiek zorgde de comparatieve en dynamische aanpak voor een gedetailleerd begrip van de obesitasgerelateerde sterftelelast en de ontwikkeling ervan. Het opnemen van geboortecohorten in een onderzoek dat zich richt op obesitasgerelateerde sterfte is nieuw voor Europa. Bovendien wordt een nieuwe extrapolatietechniek gebruikt om voorspellingen op de lange termijn te doen. Dit promotieonderzoek heeft echter ook beperkingen, waarvan de belangrijkste voortkomen uit de gebruikte data. Een groot deel van de gebruikte data (m.b.t. obesitasprevalentie, relatieve risico’s en doodsoorzaakspecifieke sterfte) heeft belangrijke beperkingen. Nader onderzoek zal daarom baat hebben bij studies die zich richten op lacunes in de beschikbare data en zo bijdragen aan het verbeteren van schattingen van obesitasgerelateerde sterfte.

De resultaten van dit onderzoek hebben belangrijke consequenties omdat ze laten zien dat obesitas en de daarmee gepaard gaande lasten meer aandacht verdienen van de samenleving als geheel en van beleidmakers. Er zijn effectieve gezondheidsinterventies nodig om de verdere toename van obesitas te stoppen. De grote variatie in obesitas en de obesitasgerelateerde sterftelelast tussen Europese landen laat zien dat verschillende strategieën ontwikkeld moeten worden voor verschillende landen. Daarnaast zijn ook interventies op diverse schaalniveaus (landelijk, individueel) nodig om de vele.
verschillende oorzaken van obesitas aan te pakken. De invloed van geboortecohorten zoals aangetoond in dit onderzoek laat zien hoe belangrijk interventies op jonge leeftijd zijn om bij te dragen aan de ontwikkeling van blijvende, gezonde leefgewoonten. Zulke gezondheidsinterventies zijn niet alleen essentieel om de obesitasepidemie te bestrijden maar ook om de gezondheid en het welzijn van Europese samenlevingen, nu en in de toekomst, te verbeteren.
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About the author

Nikoletta Vidra holds a bachelor (diploma) in Nutrition Science and Dietetics and a MSc in Human Nutrition, both from Harokopio University of Athens, Greece. Prior to her PhD, she worked as a researcher on nutritional epidemiology for five years in various projects, in Harokopio University and Athens Medical School; and as a Nutritionist in different settings (i.e. industry, clinical practice). Nikoletta conducted her PhD dissertation at the Faculty of Spatial Sciences of the University of Groningen within the VIDI project “Smoking, alcohol and obesity – ingredients for improved and robust mortality projections” led by Prof. Fanny Janssen (see www.futuremortality.com).
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Obesity is considered a global epidemic in terms of both its prevalence and associated health burden. Although Europe has the second-highest obesity prevalence levels in the world, few studies have focused on the obesity epidemic in Europe, or on its mortality burden.

This thesis examined for Europe how obesity affects mortality levels and trends, and how obesity is likely to develop in the future, using a combination of demographic and epidemiological data and methods.

In 2012, the share of mortality due to obesity (obesity-attributable mortality fraction) was, on average, 10% in the 26 European countries studied. If obesity was eliminated, life expectancy would, on average, increase 1.22 and 0.98 years among men and women, respectively. The mortality burden of obesity was slightly lower in Western than in Eastern Europe. Within Western Europe, the UK had the largest mortality burden. The mortality burden of obesity has been increasing over time, with important cohort effects. The obesity epidemic in Europe is expected to reach its peak between 2026 and 2054, with prevalence levels of at least 25%.

The mortality burden of obesity in Europe is significant, with clear variations between countries. The UK seems to be the forerunner in obesity levels in Western Europe, and to be following US trends. The variations observed between European countries can be linked to both contextual factors (e.g., obesogenic environment) and individual factors (e.g., dietary and physical activity patterns). Obesity and its associated mortality burden in Europe are problems that clearly warrant further attention from society and health policy-makers.