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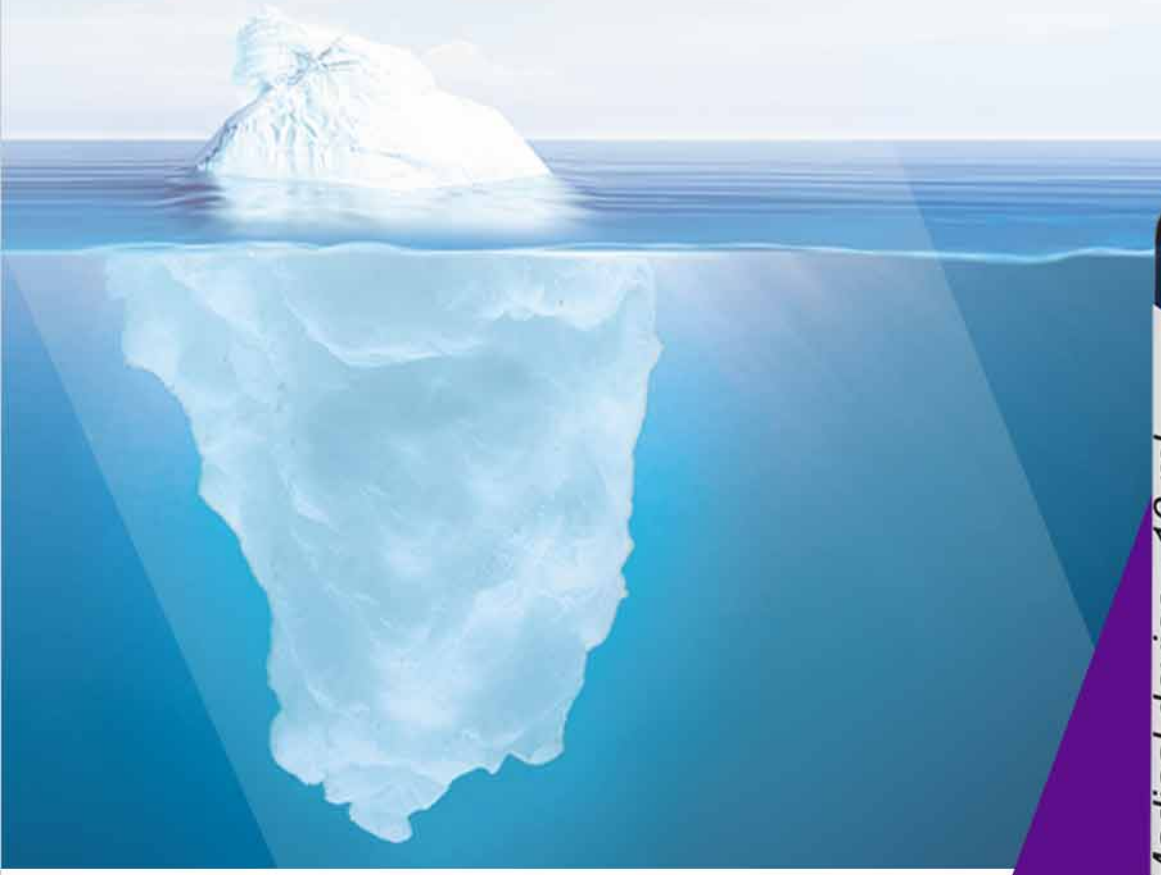

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Original article

Mortality from abdominal aortic aneurysm: trends in European Union 15+ countries from 1990 to 2017

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Background: This observational study assessed trends in abdominal aortic aneurysm (AAA) death rates in European Union (EU) 15+ countries for the years 1990 to 2017.

Methods: Age-standardized death rates (ASDRs) were extracted from the Global Burden of Disease Study Global Health Data Exchange. Trends were analysed using joinpoint regression analysis.

Results: Between 1990 and 2017, ASDRs from AAA decreased in all 19 EU15+ countries for women, and in 18 of 19 countries for men. Increasing AAA mortality was observed only for men in Greece (+5·3 per cent). The largest relative decreases in ASDR between 1990 and 2017 were observed in Australia (men −65·6 per cent, women −50·4 per cent) and Canada (men −60·8 per cent, women −48·6 per cent). Over the 28-year interval, the smallest decreases in ASDR for women were noted in Greece (−2·3 per cent) and in Italy (−2·5 per cent). In 2017, the highest mortality rates were observed in the UK for both men and women (7·5 per 100 000 and 3·7 per 100 000 respectively). The lowest ASDR was observed in Portugal for men (2·8 per 100 000) and in Spain for women (1·0 per 100 000). ASDRs for AAA in 2017 were higher for men than women in all 19 EU15+ countries. The most recent trends demonstrated increasing AAA ASDRs in 14 of 19 countries for both sexes; the increases were relatively small compared with the improvements in the preceding years.

Conclusion: This observational study identified decreasing mortality from AAA across EU15+ countries since 1990. The most recent trends demonstrated relatively small increases in AAA mortality across the majority of EU15+ countries since 2012.

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Introduction

The prevalence of abdominal aortic aneurysm (AAA) is derived from population-based screening studies, which report overall rates from 1·9 to 18·5 per cent in men and 0–4·2 per cent in women, depending on age[1]. The risk of death from AAA increases with increasing aneurysm diameter[1].

Risk factors found to be associated with the development of AAA include age, sex, smoking and hypertension[1,2]. Sidloff and colleagues[3] have shown that mortality rates from AAA vary between nations. In the UK, significant declines in AAA mortality for both men and women have been reported[4–6]. No recent analysis has compared trends in AAA mortality in countries with higher health expenditure; nor have data collected from the Global Burden of Disease (GBD) Study[7] been used to assess trends in AAA mortality.

The primary objective was to assess the trends in mortality from AAA in the European Union (EU) 15+ countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, UK and USA). This group of countries has been used in previous observational reports[8,9] because of their similarities in health expenditure and comparability. This was an observational study of the GBD database[7] to compare mortality rates from AAA in EU15+ countries between 1990 and 2017.

Methods

Methodology for the GBD Study has been published previously[7]. The GBD Study data are estimated annually, and each round of results is internally consistent

(cause-specific mortality estimates match all-cause mortality estimates). The data are freely accessible (http://ghdx.healthdata.org/gbd-results-tool). The GBD Study attributes each death to a single underlying cause that began the series of events leading to death, in accordance with the principles of ICD-10. For the present report, cases for which the single underlying cause of death was recorded as AAA were extracted.

The GBD cause-of-death database is derived from seven different types of data source: vital registration (VR), verbal autopsy (VA), cancer registry, police records, sibling history, surveillance and survey/census. VR data obtained from the WHO Mortality Database represent the source for most cause-of-death data, with individual countries submitting a compilation of data to the WHO each year. Additional VR data are identified and obtained from country-specific mortality databases operated by official offices. The GBD Study[7,10] has created a map that permits ICD-9 and ICD-10 codes to be translated to GBD causes; GBD mapping of deaths to causes lists adjusts for differing coding systems.

The quality of mortality data available in each country was characterized by the GBD authors, who analysed the accessibility and completeness of VR and VA data for each location-year between 1980 and 2017. VR data represent the most comprehensive, and therefore the highest-quality, data. All of the EU15+ countries have at least 90 per cent VR and VA completeness for each of the years assessed from 1990 to 2017. The GBD Study also grades the reliability of annual cause of death estimates on a scale from 0 to 5 stars[7]. Ten of the 19 EU15+ countries were graded as 5 stars (Australia, Austria, Canada, Finland, Ireland, Italy, Norway, Sweden, UK and USA), with 85–100 per cent of mortality data well certified. The other nine EU15+ countries (Belgium, Denmark, France, Germany, Greece, Luxembourg, Netherlands, Portugal and Spain) were graded as 4 stars, with 65–84 per cent of data well certified.

Data handling

Age-standardized mortality for AAA as the underlying cause of death per 100 000 population, categorized by EU15+ country, sex and year (1990–2017), was extracted from the GBD Results Tool web-based system: the Global Health Data Exchange. For all age-standardized rates, GBD uses a standard population calculated as the non-weighted average across all countries of the percentage of the population in each 5-year age group for the years 2010–2035 from the United Nations Population Division's World Population Prospects (2012 revision)[11]. The difference between the start and end age-standardized death rates (ASDRs) for both men and women in each EU15+ country was calculated to determine the absolute and relative changes in ASDRs over the observation interval.

Statistical analysis

Joinpoint software (Joinpoint Command Line version 4.5.0.1) provided by the US National Cancer Institute Surveillance Research Program[12] was used to assess mortality trends. Joinpoint regression is a trend analysis that takes data and fits the simplest model. The analysis starts with the minimum number of joinpoints (for example, 0 joinpoints, which is a straight line) and tests whether more joinpoints are statistically significant and must be added to the model (up to the maximum number)[12]. A Monte Carlo permutation method is used to test for significance, Furthermore, the software calculates the estimated annual percentage change (EAPC) for each line segment with 95 per cent confidence intervals. The null hypothesis is: no change. EAPCs are evaluated to determine whether a difference exists from this null hypothesis. In the final model, each joinpoint represents a statistically significant change in trend (increase or decrease), and each trend is described by an EAPC with confidence estimates. The EAPC allows assessment of trend changes at a constant percentage per year.

Results

Over the 28-year interval studied, changes in mortality rates from AAA were observed across EU15+ countries for both men and women. In 2017, the mean ASDRs for women and men were 2·1 per 100 000 and 5·0 per 100 000 respectively.

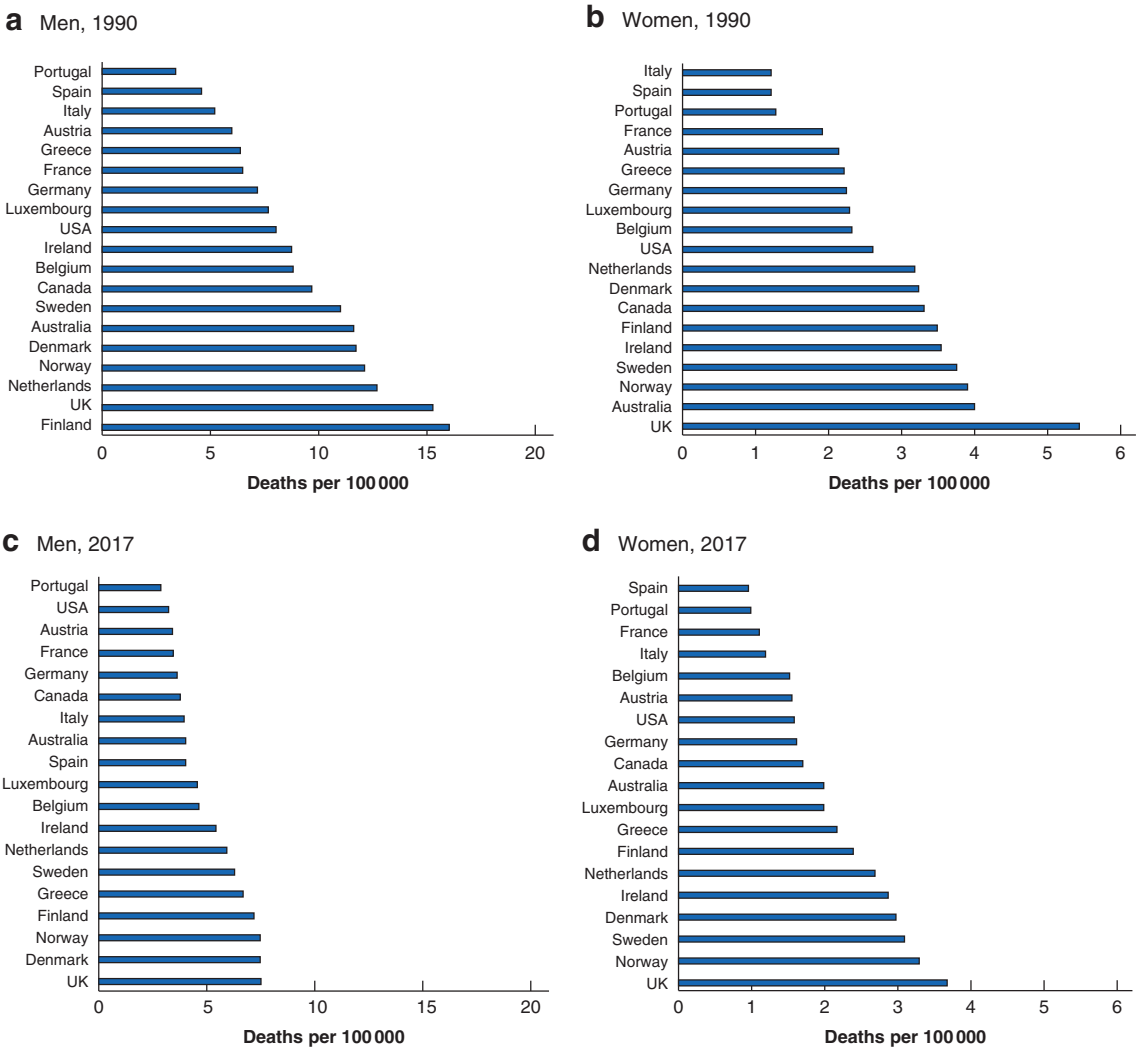
Mortality from abdominal aortic aneurysm in 2017

ASDRs per 100 000 for men and women by country in 2017 are shown in *Fig. 1a,b*. In 2017, the highest ASDRs were observed in the UK (7·5 per 100 000 and 3·7 per 100 000 for men and women respectively). The lowest ASDR was observed in Portugal for men (2·8 per 100 000) and Spain for women (1·0 per 100 000). ASDRs for AAA in 2017 were higher in men than women in all 19 EU15+ countries.

Trends in abdominal aortic aneurysm mortality

AAA ASDRs from 1990 to 2017 for both men and women in each EU15+ country are presented in *Fig. 2*. In women, the overall trends in ASDRs showed a decrease in all 19

Fig. 1 Age-standardized mortality rates per 100 000 from abdominal aortic aneurysm in EU15+ countries in 1990 and 2017, for men and women



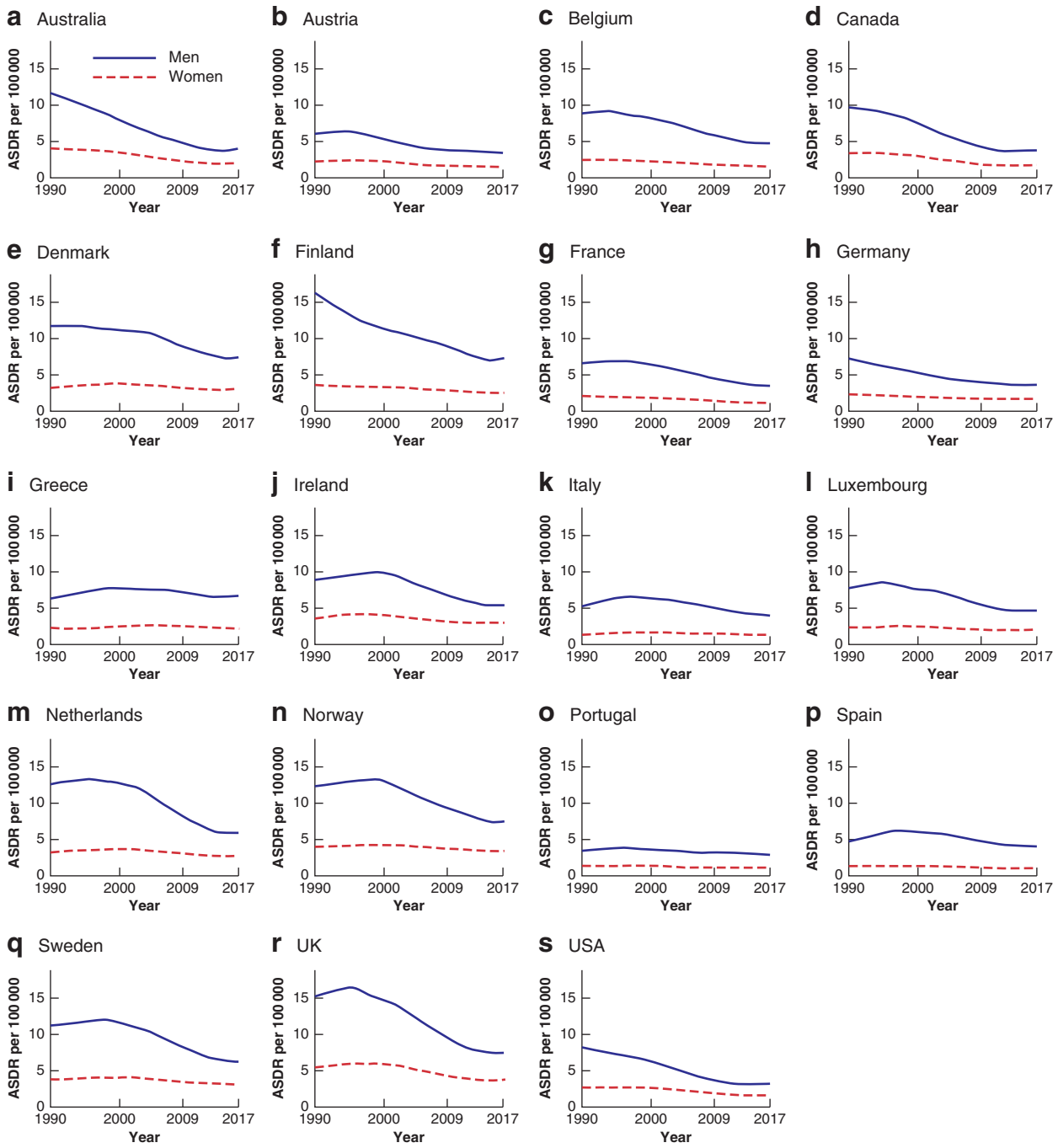
a Men, 1990; **b** women, 1990; **c** men, 2017; **d** women, 2017.

EU15+ countries. For men, mortality trends showed a decrease in 18 of the 19 countries. Only Greece had an increasing trend between 1990 and 2017 (5·3 per cent increase in ASDR between 1990 and 2017). The largest relative decreases in ASDRs between 1990 and 2017 were observed in Australia (men −65·6 per cent, women −50·4 per cent) and in Canada (men −60·8 per cent, women −48·6 per cent). For women, over the 28-year interval the smallest decreases in ASDR were noted in Greece (−2·3 per cent) and in Italy (−2·5 per cent).

Joinpoint analyses for ASDRs in individual EU15+ countries between 1990 and 2017 are shown for men and women in *Tables 1* and *2* respectively. Significant trend changes in ASDRs were identified in all EU15+ countries. Mortality trends were variable, but an overall downward trend was noted. The most rapidly decreasing trends were observed in the mid-to-late sections of the interval studied, most notably between 2002 and 2005 for women in Norway, and between 2003 and 2014 for men in Luxembourg.

Increases in AAA ASDRs were observed in intervals covered by the most recent trends in 14 of 19 countries for both men and women. The largest increases in ASDRs were noted in the trends covering the years 2014–2017 in Australia (men +5·6 per cent, women +4·8 per cent).

Fig. 2 Trends in age-standardized mortality rates per 100 000 from abdominal aortic aneurysm in EU15+ countries between 1990 and 2017, for men and women



a Australia, **b** Austria, **c** Belgium, **d** Canada, **e** Denmark, **f** Finland, **g** France, **h** Germany, **i** Greece, **j** Ireland, **k** Italy, **l** Luxembourg, **m** Netherlands, **n** Norway, **o** Portugal, **p** Spain, **q** Sweden, **r** UK and **s** USA. ASDR, age-standardized death rate.

Table 1 Joinpoint analysis age-standardized mortality rates from abdominal aortic aneurysm in EU15+ countries, 1990–2017, among men

	Trend 1		Trend 2		Trend 3		Trend 4	
	Years	EAPC	Years	EAPC	Years	EAPC	Years	EAPC
Australia	1990–1997	−3·1*	1997–2014	−5·3*	2014–2017	+5·6*		
Austria	1990–1996	+0·5	1996–2006	−4·9*	2006–2017	−1·1*		
Belgium	1990–1994	+0·6	1994–2002	−2·2*	2002–2014	−4*	2014–2017	+1·2
Canada	1990–2004	−0·9*	2004–2015	−3·4*	2015–2017	+3·5*		
Denmark	1990–1997	−4·6*	1997–2007	−2·3*	2007–2015	−3·9*	2015–2017	+3·9*
Finland	1990–1996	+0·8*	1996–2002	−2*	2002–2014	−4·5*	2014–2017	+1·6*
France	1990–2006	−3·5*	2006–2014	−2·2*	2014–2017	+4·1*		
Germany	1990–1998	+2·5*	1998–2007	−0·3	2007–2014	−1·9*	2014–2017	+2·2*
Greece	1990–1999	+1·7*	1999–2014	−4·1*	2014–2017	+1·8		
Ireland	1990–1996	+3·9*	1996–2003	−1*	2003–2014	−3·6*	2014–2017	0
Italy	1990–1995	2*	1995–2003	−2*	2003–2013	−4·5*	2013–2017	+1·7*
Luxembourg	1990–1995	+1·2*	1995–2003	−1·3*	2003–2014	−6·1*	2014–2017	+0·4
Netherlands	1990–1999	+0·9*	1999–2015	−3·6*	2015–2017	+1·4		
Norway	1990–1996	+1·4*	1996–2006	−1·8*	2006–2009	+1·2	2009–2017	−1·1*
Portugal	1990–1996	+4·8*	1996–2003	−0·6*	2003–2013	−3·3*	2013–2017	+0·3
Spain	1990–1998	+0·9*	1998–2004	−1·8*	2004–2014	−4·6*	2014–2017	−0·5
Sweden	1990–1995	+1·4*	1995–2002	−2·3*	2002–2012	−5·4*	2012–2017	−1·4*
UK	1990–1994	−1·2*	1994–1998	−2·7*	1998–2012	−5·7*	2012–2017	+1·6*
USA	1990–1995	−1·6*	1995–2001	−3·6*	2001–2012	−5·8*	2012–2017	+0·9*

EAPC, estimated annual percentage change. *$P < 0·050$ *versus* 0 (output from joinpoint regression analysis).

Table 2 Joinpoint analysis for age-standardized mortality rates from abdominal aortic aneurysm in EU15+ countries, 1990–2017, among women

	Trend 1		Trend 2		Trend 3		Trend 4	
	Years	EAPC	Years	EAPC	Years	EAPC	Years	EAPC
Australia	1990–1999	−1·4*	1999–2014	−4·2*	2014–2017	+4·8*		
Austria	1990–1995	+1·2*	1995–2000	−1·3*	2000–2005	−4·4*	2005–2017	−0·6*
Belgium	1990–2000	−0·7*	2000–2010	−3·1*	2010–2017	−0·3		
Canada	1990–2000	+1·5*	2000–2014	−1·8*	2014–2017	+2		
Denmark	1990–1996	−3·4*	1996–2003	−0·6	2003–2015	−2·1*	2015–2017	+1·5
Finland	1990–1998	−1*	1998–2002	−2*	2002–2014	−3·3*	2014–2017	+1·5*
France	1990–1995	−3·6*	1995–2006	−1·8*	2006–2014	−0·5*	2014–2017	+3·6*
Germany	1990–1993	−1	1993–2005	+1·6*	2005–2017	−1·5*		
Greece	1990–1995	+2·8*	1995–2000	−0·4	2000–2011	−2·8*	2011–2017	+0·4
Ireland	1990–1998	+2·8*	1998–2003	−0·2	2003–2013	−2*	2013–2017	+0·3
Italy	1990–1994	−0·1	1994–1997	+3·2*	1997–2011	−2*	2011–2017	+2·3*
Luxembourg	1990–1995	+2*	1995–2002	+0·5*	2002–2015	−2·3*	2015–2017	+2·8*
Netherlands	1990–2001	+0·8*	2001–2017	−1·7*				
Norway	1990–1997	+0·2	1997–2002	−1·5	2002–2005	−6·7*	2005–2017	+0·2
Portugal	1990–1996	+0·9*	1996–2003	−1·3*	2003–2011	−2·5*	2011–2017	+0·5*
Spain	1990–2002	+0·7*	2002–2015	−2·1*	2015–2017	+2·3		
Sweden	1990–1996	+1·6*	1996–2002	−0·8*	2002–2013	−3·9*	2013–2017	−0·1
United Kingdom	1990–1995	−0·2	1995–1999	−1·9*	1999–2012	−4·8*	2012–2017	+2·4*
United States	1990–1996	+0·4	1996–2002	−1·4*	2002–2012	−4·5*	2012–2017	+0·8*

EAPC, estimated annual percentage change. *$P < 0·050$ *versus* 0 (joinpoint regression analysis).

Similar recent increases in AAA ASDRs were observed in both the UK (men +1·6 per cent, women +2·4 per cent) and the USA (men +0·9 per cent, women +0·8 per cent).

Discussion

In this observational analysis of trends in AAA mortality in EU15+ countries, decreases in mortality from AAA were observed over the 28-year interval studied for men and women in all countries, with the exception of men in Greece. The largest reductions in AAA mortality between 1990 and 2017 were noted in Australia for both sexes. In 2017, the highest ASDRs were observed in the UK for both men and women.

The observed reductions in trends in AAA mortality were generally consistent with the initial hypothesis, which was based on evidence demonstrating reductions in the global incidence and prevalence of AAA[13], and reductions in the prevalence of ruptured AAA[14–16] in Europe and the USA. In addition, the authors have previously used data from the WHO Mortality Database to demonstrate reductions in mortality from ischaemic heart disease and stroke[17], and the GBD Study[18] to show reductions in the incidence of peripheral artery disease in European countries over similar time intervals. Given the overlap of risk factors with atherosclerotic disease and AAA development and rupture[19,20], it was hypothesized that similar temporal reductions in AAA mortality would be observed. There has been a small increase in AAA ASDRs in recent years for the majority of EU15+ countries. The increases, where observed, were small compared with the decreases in AAA mortality in the preceding years.

There are multiple risk factors associated with the development and rupture of AAA. Tobacco smoking is the main modifiable risk factor, and between 18 and 25 per cent of individuals with an AAA detected on routine screening are current smokers[1]. In the UK, tobacco advertising and sponsorship has been banned by law and, since 2012, display of tobacco products at the point of sale has been outlawed[21]. Such measures helped achieve the UK government's target of reducing smoking prevalence among adults to 18·5 per cent or less by 2015; to 12 per cent or less among 15 year olds by 2015; and to 11 per cent or less among pregnant women by the end of 2015[21]. Similar tobacco control measures have been implemented by other EU15+ nations, such as Australia[22] and Canada[23].

Deaths from AAA are typically the result of aneurysm rupture; however, perioperative mortality after intervention for both unruptured and ruptured AAA also contributes to national mortality rates. Endovascular aneurysm repair (EVAR) and open surgical repair (OSR) are the two principal surgical treatment options for both unruptured and ruptured AAA.

Deaths from AAA undergoing intervention represent only a small proportion of the population mortality from aneurysm over the time interval studied here, but the use of EVAR has risen for both unruptured and ruptured AAA. In the USA, the use of EVAR increased from 5·2 per cent in 2000 (5·9 per cent for unruptured AAA, 0·8 per cent for ruptured AAA) to 74·0 per cent in 2010 (77·8 and 38·4 per cent respectively)[24]. The present observational analysis demonstrated reductions in AAA mortality trends over the same interval for both men and women in the USA.

A similar shift from OSR to EVAR for both unruptured and ruptured AAA repair has occurred globally[25–27]. The VASCUNET study[26,27] analysed outcomes of both ruptured and unruptured AAA repair in Australia, Denmark, Finland, Germany, Hungary, Iceland, New Zealand, Norway, Sweden, Switzerland and the UK, using national and regional vascular registry databases between 2005 and 2013. Increasing use of EVAR from 2005 to 2013 was observed in all included countries for both unruptured and ruptured AAA. For ruptured AAA, reductions in perioperative mortality were reported across included countries. There were reductions in AAA ASDRs over the same time interval (2005–2013) in the present analysis for the EU15+ countries that were included in VASCUNET. The 4·2 per cent overall improvement in perioperative mortality after ruptured AAA repair noted between 2005 and 2009 in the VASCUNET study was thought to be due to the increased use of EVAR for ruptured aneurysm.

Of the nine countries represented in VASCUNET, Australia undertook the highest relative percentage of EVAR for unruptured (69·7 per cent) and ruptured (39·8 per cent) AAAs between 2010 and 2013. In 2005, EVAR represented 4 per cent of repairs for ruptured AAA in Australia, rising to 39·8 per cent between 2010 and 2013. The GBD Study data analysed here showed that Australia had the largest relative reduction in AAA mortality from 1990 to 2017 for both men and women, with the most rapid decline occurring between 1997 and 2014.

The observational data concerning the potential benefit of EVAR for ruptured AAA are supported by growing evidence. An observational analysis of 49 centres worldwide demonstrated significantly lower 30-day procedural mortality in individuals treated for ruptured AAA with EVAR compared with OSR (19·7 *versus* 36·3 per cent)[25]. Furthermore, the IMPROVE trial[28] from the UK and Canada demonstrated a significant survival advantage of EVAR compared with OSR for ruptured AAA after 3 years of follow-up.

Despite the trend for overall decreases in AAA mortality between 1990 and 2017, small increases were present for 14 of 19 EU15+ countries among men and women for the most recent intervals analysed (typically 2011–2012 to 2017). These were most pronounced in Australia between 2014 and 2017 (men +5·6 per cent, women +4·8 per cent), which has comparatively high rates of EVAR use for all types of AAA[26,27]. This could have been influenced by reintervention and/or late rupture, both well described sequelae of EVAR[29–32].

The highest AAA ASDRs in 2017 were observed in the UK. The results of the VASCUNET study[26,27] demonstrated a higher risk of perioperative death after unruptured AAA repair in the UK compared with other countries in the VASCUNET collaboration. In response to the 2011 VASCUNET study, the Vascular Society for Great Britain and Northern Ireland recommended the centralization of vascular services in the UK, a model for which was proposed in 2012[33], and this was introduced along with an AAA Quality Improvement Programme[34]. The present observational analysis suggests that, despite an overall reduction in AAA ASDRs from 1990 to 2017 in the UK for both sexes, they may have increased for men and women since 2012 (2012–2017 EAPC in AAA ASDR: men +1·6 per cent, women +2·4 per cent). The explanation for this is not known.

Three of the EU15+ countries (Sweden, UK and USA) have a national population-based screening programme for AAA. Sweden and the UK offer men aged 65 years a single ultrasound examination to determine aortic diameter. In the USA, screening is recommended to individuals aged 60–85 years who have smoked over 100 cigarettes in their lifetime[35]. Thirteen-year follow-up data from the UK-based Multicentre Aneurysm Screening Study[36] demonstrated that screening significantly reduced AAA-related mortality. Significant reductions in AAA-specific mortality were also noted in Sweden following the introduction of AAA screening in 2006[37]. Screening programmes can affect the registration of aneurysm-related deaths in several ways. First, a number of ruptures will be prevented, with approximately two elective repairs resulting in one less rupture. Second, the number of recorded deaths from AAA may paradoxically increase, because some patients with a known AAA who die suddenly may have their death attributed to AAA.

Men in Greece represented the only group with increasing ASDRs between 1990 and 2017 (+5·3 per cent). Evidence to explain these results is of limited quality. Greece has one of the highest numbers of smokers in Europe[38], and increasing mortality from peripheral artery disease has been observed in Greece over the same time interval[18]. Greece does not have centralized vascular services; nor does it have an AAA screening programme.

Several limitations should be considered when interpreting the results of this study. First, the analysis compared national trends in AAA mortality over 28 years, so it is not possible to make causal statements about these data. Although some of the evidence in relation to OSR and EVAR has been highlighted, it should be remembered that this study examined trends in mortality attributed to all AAAs, not just those that underwent intervention. Second, alterations in data coding practices and systems among included studies (including transitions in the international death certification coding from ICD-9 to ICD-10 over the study interval) may have affected the data. The GBD Study maps deaths to causes lists, to adjust for differing coding systems[7–10,39]. Third, the accuracy of death certification can be variable within and across countries, and the co-morbidities that are often associated with AAA (ischaemic heart disease, cerebrovascular disease and peripheral arterery disease) can cause further complications. Only 38 per cent of deaths were registered worldwide in 2012[40]; however, Europe, the Americas and Australasia had the best performing systems for civil registration and vital statistics[40] which supports the reliability of data from the EU15+ countries included in this analysis. The GBD Study 2017[7] uses corrections for under-registration and garbage code redistribution algorithms to improve the comparability of results (garbage codes refer to deaths attributed to ill defined diagnoses or conditions that cannot be underlying causes of deaths). Finally, the observational nature of this analysis means that there are likely to be a number of unmeasured confounding factors. An important confounder is the variation in management of AAA across included countries. Despite consistent guidelines from professional societies, evidence from the International Consortium of Vascular Registries demonstrated that countries with a fee-for-service reimbursement system (including Australia, Germany and the USA) undertook more operations on small AAA and operations in octogenarians than countries with a population-based reimbursement system (such as the UK and Scandinavian countries)[41].

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Editor's comments

This paper covers what happened to abdominal aortic aneurysm (AAA) during my entire career as a vascular surgeon (and BJS editor), trying to prevent death from rupture. Aside from the wide differences in annual death rates, acknowledged as possible limitations of data recording, the importance of epidemiology over treatment is highlighted. The reported changes in death rate over time are more reliable, and suggest AAA mortality declined in parallel with the reduction in cigarette smoking habits, rather than as a result of vascular intervention or AAA screening. AAA screening is a powerful tool to prevent death from rupture, particularly in men aged 65 to 80, when arguably their quality of life is most valuably preserved. Yet, at best, AAA screening has only accelerated an existing steady decline in deaths from AAA. Screening has most to offer nations with the least change in death rate for AAA (most cigarette smokers): health services of Greece, Spain and Portugal take note! The reduction in AAA population mortality across this group of countries is welcome, and a tribute both to epidemiologists and governments fighting to reduce cigarette consumption, and vascular surgeons operating to prevent death from AAA.

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