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The Global and Regional Prevalence of Abdominal Aortic Aneurysms: A Systematic Review and Modeling Analysis

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Objective: To estimate the global and regional prevalence and cases of abdominal aortic aneurysms (AAAs) in 2019 and to evaluate major associated factors.

Background: Understanding the global prevalence of AAA is essential for optimizing health services and reducing mortality from reputed AAA.

Methods: PubMed, MEDLINE, and Embase were searched for articles published until October 11, 2021. Population-based studies that reported AAA prevalence in the general population, defined AAA as an aortic diameter of 30 mm or greater with ultrasonography or computed tomography. A multilevel mixed-effects meta-regression approach was used to establish the relation between age and AAA prevalence for high-demographic sociodemographic index and low-and middle-sociodemographic index countries. Odds ratios of AAA associated factors were pooled using a random-effects method.

Results: We retained 54 articles across 19 countries. The global prevalence of AAA among persons aged 30 to 79 years was 0.92% (95% CI, 0.65–1.30), translating to a total of 35.12 million (95% CI, 24.94–49.80) AAA cases in 2019. Smoking, male sex, family history of AAA, advanced age, hypertension, hypercholesterolemia, obesity, cardiovascular disease, cerebrovascular disease, claudication, peripheral artery disease, pulmonary disease, and renal disease were associated with AAA. In 2019, the Western Pacific region had the highest AAA prevalence at 1.31% (95% CI, 0.94–1.85), whereas the African region had the lowest prevalence at 0.33% (95% CI, 0.23–0.48).

Conclusions: A substantial proportion of people are affected by AAA. There is a need to optimize epidemiological studies to promptly respond to at-risk and identified cases to improve outcomes.

Keywords: abdominal aortic aneurysms, global burden of disease, prevalence, risk factor, systematic review

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Abdominal aortic aneurysm (AAA) is an abnormal localized dilatation of the lower part of the aorta, characterized by ≥ 1.5 times the normal aortic diameter at the renal arteries level (approximately a minimum diameter of 30 mm).[1,2] Despite the earlier reports suggesting a steadily increasing burden of AAA, in terms of new cases and deaths, data in the last 2 decades suggest otherwise, with reported steep declines in incidence and mortality, especially from Denmark, Sweden, New Zealand, the United Kingdom, and the United States.[2–5] Decreasing prevalence of tobacco smoking, as observed in some high-income countries (HICs), may have driven this decline.[6] In addition to reduced exposure to risks, the use of antihypertensives and cardioprotective medications in many HICs may have also contributed to this decline.[7] However, in many low-income and middle-income countries (LMICs), rising prevalence of smoking, hypertension, harmful use of alcohol, and many cardiovascular risk factors are continually reported, suggesting a likely increasing burden of AAA, particularly with a relatively poor overall public health response.[6,7]

Epidemiological reports on AAA vary across age, sex, and locations worldwide.[7,8] The reports from population-based screening exercises reveal a significantly higher prevalence among men, with rates in the range of 1.9% to 18.5% among men and 0.1% to 4.2% among women.[9] Most studies have identified advanced age, male sex, ever smoking, high blood pressure, and family history of AAA as the most important risk factors driving the burden of AAA.[10,11] Mortality also varies across countries, often linked to prehospital response, emergency care, hospital capacity, and intervention and repair type after AAA rupture.[7,12,13] From a meta-analysis of 24 retrospective cohort studies, an 81% fatality was reported after a ruptured AAA, with approximately a third of cases dying before getting to a hospital.[14] In the United States and the United Kingdom, deaths from ruptured AAA were estimated at 53% and 66%, respectively, with postintervention fatality in both countries estimated at 42%.[13] In 2017, the Global Burden of Disease (GBD) collaborators reported that AAA accounted for ~170,000 deaths and 3 million disability-adjusted life years worldwide.[15–17]

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Despite these figures, the true global burden of AAA remains vague. In many settings, it is only known among men.[7] Some authors noted that, despite a seemingly decreasing trend in AAA, prevalence and mortality in settings across Latin America, Asia Pacific, and Africa may be increasing.[18,19] Many have also projected that high systolic blood pressure may surpass the contributions of smoking to AAA, which is likely to lead to a rebounding trend in AAA burden and deaths.[20] This is particularly true in LMICs, where an increasing prevalence of hypertension and peripheral arterial disease is still being observed.[8,21] The GBD collaborators corroborated this, with a gradually plateauing decreasing global mortality, and an apparent increase in AAA-related mortality across Central Asia, North Africa, and Central and Eastern Europe.[15–17] Besides, smoking prevalence is gradually increasing among women in HICs would imply renewed research focus and a need to better understand AAA among women.[10] Given these observations, and findings of our recent related study on peripheral arterial disease,[21] where we observed higher prevalence among young adults in LMICs compared with HICs, we aim to estimate global and regional prevalence and the number of cases of AAA in 2019. This will provide an updated global estimate that addresses current concerns and inform necessary population-wide responses across world regions.

METHODS

This systematic review, meta-analysis and modeling study was conducted according to a preregistered protocol in PROSPERO (identifier: CRD42020207230). We have reported findings in line with the Preferred Reporting Items for Systematic Reviews and Meta-analyses guideline[22] and the Guidelines for Accurate and Transparent Health Estimates Reporting.[23]

Search Strategy and Study Selection

We systematically searched PubMed, MEDLINE, and Embase to identify sources for the prevalence of AAA in the general population from database inception until October 11, 2021. Search terms used included combinations of keyword and controlled vocabulary terms relating to AAA (eg, "abdominal aorta aneurysm" or "abdominal aortic aneurysm") and prevalence (eg, "prevalence" or "epidemiology"). Full details of the search strategies for the 3 databases are listed in the Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274. No language or geographical restrictions were applied. Reference lists of relevant reviews were also screened.[24–28] Gray literature (eg, conference abstracts, unpublished studies, or dissertations) were not searched.

Articles were retained in this review if they were observational studies of the general population and reported crude numbers of AAA cases and sample size, or relevant data (eg, crude prevalence) that allowed recalculation of these crude numbers. To reduce heterogeneity because of inconsistent case definitions, AAA should have been defined as an aortic diameter of 30 mm or greater, screened with ultrasonography or computed tomography. Studies were excluded if they were conducted in specific groups of participants who were deemed as not to be representative of the general population, such as outpatients, people with other cardiovascular diseases (CVDs), diabetes, and hypertension. Experimental studies, case reports, letters, reviews, editorials, and studies without explicit methodological descriptions were excluded. For multiple publications that were based on the same study, we considered the most comprehensive study with the largest sample size or the most recent one.

Two reviewers (Y.H. and P.S.) independently screened all titles and abstracts identified from the bibliographic searches. Full texts of potentially relevant studies were downloaded or requested from authors by online platforms (Researchgate), and further reviewed by the same 2 authors.

All disagreements regarding study eligibility were resolved by consensus through group discussions.

Data Extraction and Quality Assessment

Information extracted included first author, publication year, study name (if provided), study design, investigation location, country, investigation date, sample size, age of participants (average, median or range), the proportion of female participants, detection method, the definition of AAA, number of participants, and number of AAA cases. When available, we extracted stratified data on samples and cases by age group and sex within the same study. In the case of censoring age band (eg, above 60 year as right censoring and below 45 year as left censoring), the missing band was imputed by taking the same (or average) width reported in the same article. For articles where investigation years were not provided, they were imputed as 5 years before the publication years based on the average time lag between investigation and publication from articles with available information (Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274). Geographical (ie, countries, where investigations took place) were categorized into African region (AFR), region of the Americas (AMR), South-East Asia region, European region, Eastern Mediterranean region (EMR), and Western Pacific region (WPR) according to the World Health Organization (WHO) classification. On the basis of the sociodemographic index (SDI, a summary measure of overall development constructed from income per capita, average years of schooling, and total fertility rate) in 2019, countries were categorized into high-SDI (H-SDI) group and low-and middle-SDI (LM-SDI) group, using 0.805 as the cutoff point.[29] A subset of included articles explored associated factors of AAA using multivariable logistic regressions, from which we then extracted the corresponding odds ratios (ORs) and case definitions of the risk factors.

We assessed the quality of each included article with a quality scale (Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274) developed based on the Strengthening the Reporting of Observational Studies in Epidemiology statement.[30] The overall quality scale was composed of 5 parts, namely sample population, sample size, participation rate, outcome assessment, and analytical methods. Each part can be scored as zero (low quality), 1 (moderate quality), or 2 (high quality).

Data extraction and quality assessment were done using a standardized electronic form by 2 independent reviewers (Y.H. and P.S.). Two authors (X.Y. and Q.Y.) checked the data set for transcription errors. Disagreements at these stages were resolved by consensus.

Statistical Analysis

(1) Estimation of the global prevalence and cases of AAA in 2019

With the data extraction strategy stated above, a hierarchical data set was constructed (ie, age-specific and sex-specific prevalence estimates/points from the same study). To derive a robust estimation, we only restricted subgroups to a sample size of 20 or more. First, the relation of age and AAA prevalence was established with a multilevel mixed-effects meta-regression approach. The clustering of multiple data points from the same study or with the same country was adjusted for by adding study identification and country

identification into models as the random-effects. To fully use the hierarchical data set, we adopted a multilevel mixed-effects meta-regression approach to establish the relation between age and AAA prevalence. This epidemiological modeling was performed for males and females in H-SDI and LM-SDI groups, respectively. Given that more than two thirds of the extracted data points were from H-SDI countries, 2 assumptions were applied to impute data points for LM-SDI countries: (1) prevalence before age 30 was zero; (2) the prevalence in males was 5 times that in women within the same investigation (based on relevant data from H-SDI countries). To enable the inclusion of zero cases as reported, we replaced zero cells with a value of 0.0005. The age range for estimation was set as 30 to 79 years.

Then, the numbers of people affected by AAA in H-SDI countries ("H-SDI AAA envelope") and LM-SDI ("LM-SDI AAA envelope") were generated by multiplying the age-specific and sex-specific prevalence of AAA by corresponding population data in 2019 from the United Nations Population Division.[31] We estimated the global cases of AAA cases from the sum of the "H-SDI envelope" and "LM-SDI envelope" subestimates.

(2) Meta-analysis of associated factors of AAA

The ORs of associated factors of AAA, as reported in at least 3 individual articles, were synthesized using the DerSimonian and Laird random-effects method of meta-analysis.[32] Between-study heterogeneity was evaluated by Cochran Q test and I^2statistic. The I^2 represents the percentage of total variation across studies because of true between-study differences rather than chance. An I^2 of $>75\%$ indicated substantial heterogeneity.[33]

(3) Estimation of the regional prevalence and cases of AAA in 2019

In line with our series papers on peripheral artery disease and carotid atherosclerosis,[21,34] the regional number of AAA cases was estimated using a "risk factor–based" model. Given that where N_{region} refers to the number of AAA cases in each WHO region, Pop_{region} is the regional population aged 30 to 79 years, $Prev_{AAA_{world}}$ indicates the global AAA prevalence. $F_l - F_n$ refer to the selected risk factors, $Prev_{F_{region}}$ is the prevalence of the selected factor in each WHO region and $Prev_{F_{world}}$ is the global prevalence of the selected factor. $OR_{F_{world}}$ is the meta-OR of the selected factor based on our meta-analyses of associated factors. Finally, the regional AAA cases in H-SDI and LM-SDI groups were adjusted by multiplying an "adjustment index" to exactly fit into the corresponding "AAA envelopes."

$$N_{region} = \left(Pop_{region}\right)*\left(Prev_{AAA_{world}}\right) *\left(1 + \sum_{F_l}^{F_n}\left[\left(Prev_{F_{region}} - Prev_{F_{world}}\right)*\left(OR_{factor_{world}} - 1\right)\right]\right)$$

Four factors, including current smoking, hypertension, diabetes, and hypercholesterolemia, were selected and their latest prevalence rates were obtained from the WHO report on the global tobacco epidemic[35,36] and the WHO Global Health Observatory data repository.[37] Within H-SDI group and LM-SDI group, respectively, the AAA envelopes were split into the 6 WHO regions. The number of AAA cases in a specific WHO region was the sum of these in H-SDI and LM-SDI groups. The prevalence of AAA in the 6 WHO regions were generated by dividing the number of AAA cases by the mid-year population aged 30 to 79 years.

The overall study approach has been described in detail in the Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274. All analyses were conducted in STATA version 14.0 (STATA Corporation) and R version 3.3.0 (R Foundation for Statistical Computing).

RESULTS

Of 2842 records identified in the literature search, 54 articles providing 155 sex-specific prevalence estimates were retained (Fig. 1). Characteristics of the included articles are provided in the Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274. The selected studies were all cross-sectional in design and published between 2000 and 2021, covering 62,758 AAA cases from 6,785,523 participants across 19 countries. The geographic locations are shown in Figure 2. Forty-seven (87%) of the 54 included articles were assessed to have a quality score of 6 or above (Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274).

On the basis of the extracted sex-specific data points and imputed data points (193 in total, 155 extracted and 38 imputed), the relations between age and AAA prevalence in H-SDI and LM-SDI countries are demonstrated in Figure 3. The prevalence of AAA was relatively low until around 60 years, when it started to steeply increase. The increasing trend of AAA prevalence with advanced age was similar between H-SDI and LM-SDI groups, but became more pronounced in older females aged 70 years and above compared with their male counterparts. Noteworthy, the prevalence of AAA in males was much higher than that in females, across H-SDI and LM-SDI countries. In 2019, the prevalence of AAA in people aged 30 to 79 years globally was 0.92% (95% CI, 0.65–1.30). It was 3.7-times greater in males than in females [1.46% (95% CI, 1.04–2.05) vs 0.39% (95% CI, 0.27–0.56)]. After applying the demographic profile in 2019, these translated to a total of 35.12 million (95% CI, 24.94–49.80) people aged 30 to 79 years that were living with AAA in 2019. Among the affected cases, around 79% were males [27.71 million (19.71–38.99)]. The age-specific and sex-specific prevalence rates of AAA at the global level are listed in Table 1.

Because of data availability and heterogenous definition across studies, a total of 14 associated factors of AAA were evaluated in meta-analysis. Advanced age, male sex, hypertension, hypercholesterolemia, obesity, smoking (ever, former or current), family history of AAA, CVD, cerebrovascular disease, claudication, peripheral artery disease, pulmonary disease, and renal disease were all revealed to be significantly associated with a higher odds of AAA, whereas diabetes was negatively associated with AAA (Table 2). Contributing articles for every factor and the corresponding process of meta-analysis are provided in the Appendix, Supplemental Digital Content 1, http://links.lww.com/SLA/E274.

On the basis of the "risk factor model" that took into account the regional prevalence variations of current smoking, hypertension, diabetes, and hypercholesterolemia, the numbers of people with AAA in the 6 WHO regions were estimated (Table 3). In 2019, WPR had the largest number of AAA cases [16.27 million (95% CI, 11.61–22.90)], whereas AFR had the least [1.16 million (95% CI, 0.81–1.70)]. Similarly, the prevalence of AAA was the highest in the WPR [1.31% (95% CI, 0.94–1.85)], but the lowest in the AFR [0.33% (95% CI, 0.23–0.48)].

DISCUSSION

In this study, we have extracted data on AAA prevalence and associated factors spread over 2 decades (2000-2021), and

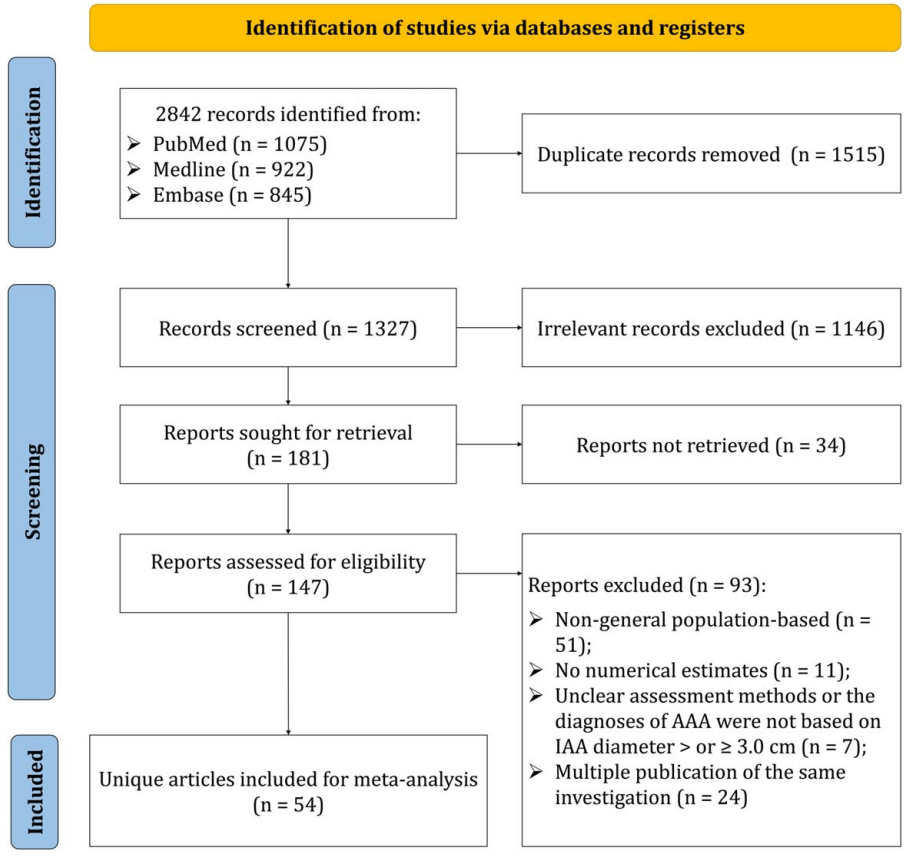

FIGURE 1. Flow diagram of study selection. IAA indicates iliac artery aneurysm.

involving ~63,000 AAA cases and 6.8 million participants from 19 countries. We used a meta-regression model on extracted multiple (hierarchical) data points on prevalence, with a global prevalence of AAA estimated at 0.92% (95% CI, 0.65–1.30) translating to 35.12 million (95% CI, 24.94–49.80) AAA cases among persons aged 30 to 79 years in 2019. We estimated the

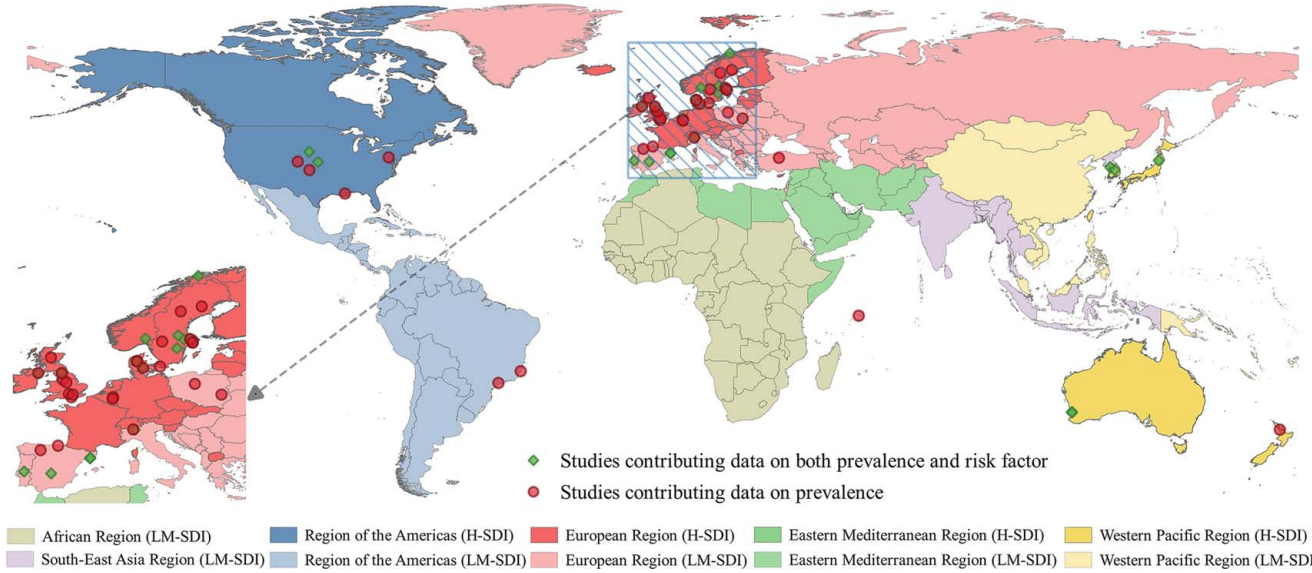

FIGURE 2. Location of included articles reporting the prevalence of AAA and associated factors.

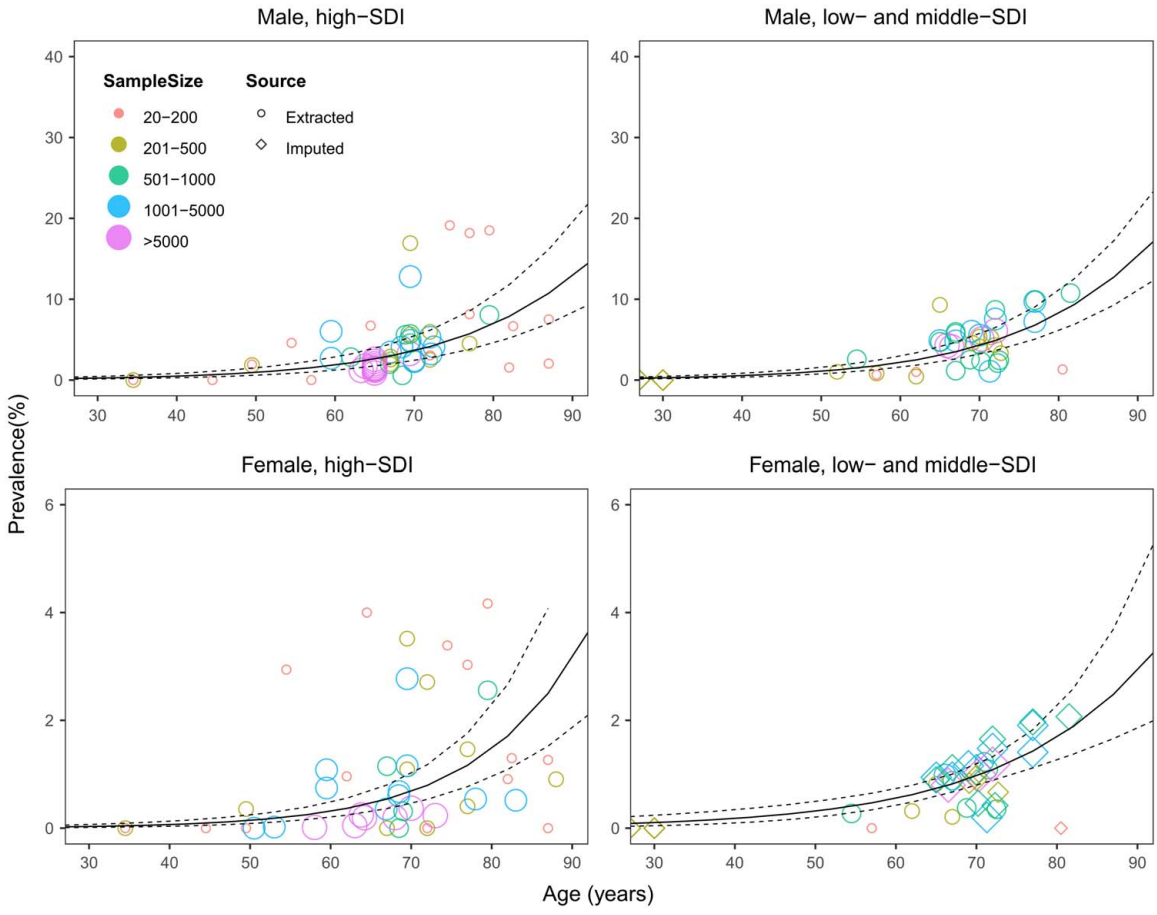

FIGURE 3. Prevalence of AAA in H-SDI and LM-SDI countries, by age and sex group. Solid lines are prevalence estimates, with dashed lines indicating 95% CI. Each circle represents a contributing data point.

highest and lowest prevalence (and cases) in WPR and AFR, respectively, with an overall 4-times higher rate in men compared with women. The young-aged to middle-aged groups in AFR and AMR are most affected with the most cases among persons under 50 years. Multiple factors, such as advanced age, male sex, CVDs, and CVD risks, were revealed to be positively associated with AAA, but diabetes was negatively associated with AAA. Overall, this study provides up-to-date estimates that can inform research, policy, and intervention globally.

There are several limitations in the understanding of the current global prevalence of AAA from the literature. First, most studies have explored repairs/surgeries, hospitalizations, and mortality mainly, with many assumptions from this on actual disease prevalence.[15–17] Second, the most comprehensive studies on AAA epidemiology have been mainly conducted in Europe and the United States, which to date, largely suggest a declining prevalence of AAA in the past 2 decades.[2] Sidloff et al[7] explored the WHO InfoBase and reported substantial

TABLE 1. Estimated Prevalence and Number of Cases of AAA in People Aged 30 to 79 years Worldwide, by Age Group and Sex

	Prevalence of AAA (%)			People with AAA (millions)		
Age group, y	**Male**	**Female**	**Overall**	**Male**	**Female**	**Overall**
30-34	0.31 (0.19-0.52)	0.11 (0.05-0.24)	0.21 (0.12-0.38)	0.96 (0.58-1.58)	0.32 (0.15-0.72)	1.28 (0.73-2.29)
35-39	0.44 (0.28-0.70)	0.15 (0.07-0.29)	0.30 (0.18-0.50)	1.21 (0.76-1.91)	0.39 (0.19-0.78)	1.59 (0.96-2.69)
40-44	0.62 (0.41-0.95)	0.19 (0.11-0.35)	0.41 (0.26-0.65)	1.54 (1.01-2.35)	0.46 (0.26-0.85)	2.00 (1.27-3.19)
45-49	0.88 (0.60-1.30)	0.25 (0.15-0.42)	0.57 (0.38-0.86)	2.10 (1.43-3.09)	0.60 (0.36-0.99)	2.70 (1.79-4.08)
50-54	1.24 (0.87-1.77)	0.34 (0.22-0.51)	0.79 (0.55-1.14)	2.73 (1.91-3.90)	0.74 (0.49-1.12)	3.48 (2.41-5.03)
55-59	1.75 (1.25-2.43)	0.45 (0.32-0.62)	1.09 (0.78-1.52)	3.32 (2.38-4.62)	0.86 (0.62-1.20)	4.18 (3.00-5.82)
60-64	2.45 (1.79-3.35)	0.59 (0.45-0.77)	1.50 (1.11-2.03)	3.81 (2.78-5.21)	0.96 (0.74-1.25)	4.77 (3.52-6.47)
65-69	3.43 (2.53-4.64)	0.78 (0.63-0.98)	2.05 (1.54-2.73)	4.38 (3.23-5.92)	1.09 (0.88-1.36)	5.47 (4.10-7.28)
70-74	4.75 (3.50-6.44)	1.03 (0.83-1.30)	2.75 (2.06-3.67)	4.10 (3.02-5.55)	1.04 (0.83-1.30)	5.14 (3.85-6.86)
75-79	6.57 (4.80-8.94)	1.38 (1.05-1.81)	3.67 (2.71-4.97)	3.56 (2.60-4.85)	0.94 (0.72-1.24)	4.50 (3.32-6.08)
Total (30-79) in 2019	1.46 (1.04-2.05)	0.39 (0.27-0.56)	0.92 (0.65-1.30)	27.71 (19.71-38.99)	7.41 (5.23-10.81)	35.12 (24.94-49.80)

TABLE 2. Synthesized Effect Size of Associated Factors of AAA That Were Investigated in at Least 3 Studies Using Multivariable Logistic Regression

Associated factor	No. Studies	Meta-OR (95% CI)	I^2	*P* for Q test
Factor 1: age (per 10-year increase)	4	2.42 (1.82-3.23)	65.3	0.034
Factor 2: male sex	4	5.71 (5.57-5.85)	30.0	0.232
Factor 3: diabetes	7	0.73 (0.54-0.98)	68.5	0.004
Factor 4: hypertension	10	1.52 (1.27-1.82)	71.4	< 0.0001
Factor 5: hypercholesterolemia	7	1.34 (1.31-1.37)	0.0	0.521
Factor 6: obesity (BMI ≥ 25 kg/m^2)	3	1.20 (1.18-1.23)	68.2	0.043
Factor 7: smoking				
Ever	7	3.77 (3.18-4.47)	0.0	0.499
Former	4	2.68 (2.29-3.14)	60.3	0.056
Current	7	4.70 (3.94-5.62)	83.0	< 0.0001
Factor 8: family history of AAA	5	3.76 (3.62-3.91)	71.5	0.007
Factor 9: cardiovascular disease	10	1.73 (1.69-1.76)	37.0	0.112
Factor 10: cerebrovascular disease	3	1.18 (1.15-1.22)	0.0	0.382
Factor 11: claudication	5	1.48 (1.21-1.83)	0.0	0.526
Factor 12: peripheral artery disease	3	1.59 (1.54-1.65)	53.9	0.114
Factor 13: pulmonary disease	4	1.26 (1.02-1.57)	28.9	0.239
Factor 14: renal disease	3	2.84 (1.35-5.97)	0.0	0.856

The definitions of some factors varied slightly across studies. ORs for binary variable factor indicated the risk of AAA compared with those without the factor, except for ever smoking (vs never smoking), former smoking (vs never smoking), current smoking (vs never smoking).

BMI indicates body mass index.

heterogeneity in AAA burden across 19 countries, with a national decline across database mainly limited to the United States and the United Kingdom, but with an increasing AAA mortality observed in Austria, Denmark, Hungary, and Romania. Among persons aged 60 years or older, current global prevalence rates have been estimated in the range of 1.2% to 3.3%,[1] which is relatively close to our current estimates. In a 2013 meta-analysis of 56 studies,[26] a prevalence of 4.8% (95% CI, 4.3–5.3) was estimated, although it seems the relatively higher estimate may be because of a not well-defined study population from the selected studies, such as elderly and men, and a mix of cross-sectional, randomized controlled trials, and prospective cohort studies. Although this may still highlights the observations on the global variations in AAA prevalence, as another study estimated quite low prevalence rates in 2010 ranging from 7.88/100,000 (95% CI, 6.54–9.59) to 2274.82/100,000 (95% CI, 2149.77–2410.17) among persons aged 40 to 44 and 75 to 79 years, respectively.[24]

Although advanced age is a major risk and reflects across both sexes in the prevalence and cases estimated in this study, the number of AAA cases in AFR and EMR seems to be more in the young to middle-age groups, with the largest cases estimated among persons under 50 years in the 2 regions. We acknowledge that this may stem from the younger populations in these settings, for example, the average life expectancy at birth for sub-Saharan Africa is under 62 years.[31] We reported approximately a 4 times higher prevalence rate in men compared with women. This is very much in keeping with existing literature. For example, in 2002, the Chichester trial reported a 6 times higher prevalence among men than observed among women in the general population,[38] whereas a 2016 review reported that men aged 65 years or older had a 3 to 4 times higher prevalence than women of the same age.[39] Although it seems the immunomodulating effects of estrogen has some protective effects that explain the lower prevalence, women generally have a more aggressive natural history once AAA develops. Some authors have also suggested that the effects of smoking on AAA among women seem to be much stronger.[40] They note that women, although much more likely to desire to quit smoking, do find it harder quitting compared with men,[40] which perhaps apparently explains the aggressiveness of AAA among women. The fact that the GBD Tobacco Collaborators noted smoking prevalence among females only decreased significantly in 33% of world countries, and exceeding a prevalence of 20% in more than 40 countries calls for concerns[41]—in terms of understanding AAA burden among women and responding appropriately.

Family history of AAA, which also returned higher pooled odds for AAA in this study, has long been identified as an important risk factor for AAA, characterized by more rapid growth and a higher rate of rupture of the aneurysm even at smaller diameters and younger ages.[10] It forms an important consideration in current screening recommendations for AAA,[2] although eliciting this history may be difficult in the population, except from relatives with first-hand experience or knowledge of

TABLE 3. Regional Prevalence and Cases of AAA in 2019, by Sex

Region	Prevalence of AAA (%)			People with AAA (millions)		
	Male	Female	Overall	Male	Female	Overall
AFR	0.37 (0.26-0.52)	0.29 (0.20-0.44)	0.33 (0.23-0.48)	0.63 (0.45-0.89)	0.53 (0.36-0.80)	1.16 (0.81-1.70)
AMR	0.67 (0.48-0.93)	0.46 (0.33-0.67)	0.56 (0.40-0.80)	1.09 (0.78-1.51)	0.82 (0.58-1.19)	1.91 (1.36-2.70)
SEAR	1.10 (0.79-1.54)	0.33 (0.23-0.49)	0.72 (0.51-1.02)	5.52 (3.95-7.72)	1.64 (1.15-2.41)	7.16 (5.10-10.14)
EUR	1.75 (1.22-2.50)	0.57 (0.41-0.82)	1.13 (0.80-1.63)	4.91 (3.43-7.03)	1.76 (1.25-2.53)	6.67 (4.69-9.56)
EMR	0.96 (0.68-1.36)	0.30 (0.21-0.46)	0.64 (0.45-0.92)	1.51 (1.07-2.14)	0.44 (0.31-0.67)	1.95 (1.38-2.81)
WPR	2.26 (1.61-3.16)	0.36 (0.26-0.52)	1.31 (0.94-1.85)	14.05 (10.02-19.69)	2.22 (1.58-3.20)	16.27 (11.61-22.90)

EUR indicates European region; SEAR, South-East Asia region.

the disease. Other positively associated factors we reported in this study, including hypertension, hypercholesterolemia, obesity, peripheral artery disease, and pulmonary disease have been previously identified in the literature, with the effects on AAA not substantially different in both sexes.[28,42] The negative association between diabetes and AAA, as revealed in this study and many epidemiological and experimental studies, challenges the traditional view of AAA as a manifestation of atherosclerosis. However, this does not necessary imply that hyperglycaemia protects AAA.[43,44] Research on precise mechanism and individualized best treatment choice for diabetic AAA patients is still needed.

Regional differences in AAA prevalence have been thought to mirror the differences in smoking prevalence and traditional cardiovascular risks in the respective regions.[7] This is relatively true in this study with higher estimates of AAA observed in WPR and South-East Asia region reflective of the high smoking prevalence in countries like China, India, Indonesia, and Timor-Leste, as observed from the GBD 2019 Tobacco Collaborators study.[41] Although smoking prevalence in many settings in Africa is comparatively lower, we acknowledge that scarcity of data on AAA prevalence from these settings may be partly responsible for the lower prevalence and cases we estimated. In the United States, ~1.1 million cases of AAA were estimated in 2008,[10] and in 2013, 2.34 million prevalent cases of AAA were reported in another modeling study.[45] These are also relatively comparable to the current estimates for AMR, largely from studies in the United States and Brazil, at 1.91 (95% CI, 1.36–2.70) million cases. Although without specific prevalence estimates, the general observation across 19 European Union countries between 1990 and 2012 was that of decreasing mortality, with a relatively small increase in mortality only observed after 2012 in 14 out of 19 countries.[9]

The limitations of this study are mainly related to a lack of data on the prevalence of AAA in many less-developed settings. Although we endeavored to address this with statistical assumptions for LM-SDI countries, these could have affected our estimates at the regional level. Besides, definitions of associated factors varied across studies, although we tried to only included studies with similar assessments and definitions, bias introduced by heterogenous definitions could not be eliminated. In addition, extracted data on associated factors across studies were also sketchy for many countries. Furthermore, the effect of identified associated factors might have been largely influence by males as a result of the predominance of males in the studied populations. We also note that there are several important factors beyond current smoking, hypertension, diabetes, and hypercholesterolemia, which we could have incorporated into our model. Socioeconomic status, social deprivation, and ethnicity have been indicated in some studies as important drivers of incidence, screening uptake, survival, and mortality from AAA, in perhaps what is similar to inequalities reported for other cardiovascular health outcomes.[46–48] Although we could not account for these, we incorporated SDIs, which explores income per capita, average years of schooling, and total fertility rate across countries, into our regional models and applied this to derive estimates for the year 2019. This has been applied in our previous estimates[21,34] and had also been used by the GBD collaborators across several studies.[15–17,41]

As observed in previous reviews,[7,24,26] we note that most epidemiological studies on AAA are premised on a background of population-based or hospital-based screening exercises to detect cases. Subsequent studies, particularly in LMICs, may therefore potentially offer ample opportunities to harness research, screening, treatment, and care in a way that could benefit the population. For example, by mobilizing and supporting available interdisciplinary expertise in epidemiology, genetics, and biomarkers, and imaging to improve the detection of AAAs at risk of progression and rupture, reevaluation of suspected cases, and prompt referral and care of established cases.[42] This has reportedly been useful, as studies have shown that early detection of persons at risk using relatively simple and inexpensive diagnostic tests with appropriate medications or surgical treatment of cases averts deaths and other complications from AAA, which is more prevalent in many resource-constrained settings.[49]

Smoking is an important and modifiable risk factor associated with almost all stages in the pathogenesis of AAA, including development, expansion, rupture, and even death,[50] making it a useful target in the response to AAA. Although the cumulative risk over the years even after quitting smoking cannot be ruled out, the benefits of smoking cessation in reducing the risk of AAA abound, as partly supported in the current study where we estimated a significantly lower pooled ORs among former smokers (2.68, 95% CI, 2.29–3.14) compared with current smokers (4.70, 95% CI, 3.94–5.62). In terms of the specific response, smoking is indicated across all levels of the US Preventive Services Task Force recommendations, with a 1-time screening for AAA by ultrasonography recommended in asymptomatic men aged 65 to 75 years that have ever smoked, and selectively for those that have never smoked.[2] Implementing this remains a major challenge in many low-income settings,[49] which still highlights our earlier above recommendations on harnessing opportunities from research within the resources available.

Although we could not account for sex differences in the contributions of smoking to the global prevalence of AAA, we note from our observations in the literature that women still form an important part of the response to AAA. The US Preventive Services Task Force stated that current evidence for routine screening for AAA among women who have never smoked is insufficient,[2] this rather reaffirms the limited research among women and an important implication for policy and practice, particularly with a relatively increasing smoking prevalence and use of tobacco products among women in many world settings.

In summary, a substantial global burden of AAA is revealed globally. Importantly, the relatively large number of AAA cases in AFR and EMR in the young-age to middle-age groups makes the 2 regions an important target for response. We also reaffirm the importance of smoking, male sex, and family history as leading risks of AAA globally, with the WPR the most affected region globally. We note a need to optimize epidemiological studies and existing structures for research in LMICs and resource-limited populations to promptly respond to at-risk and identified cases to improve outcomes. Although data from many countries remain patchy, our study has included the most up-to-date data set from available evidence on AAA prevalence and associated factors that can inform a much needed public health response and further research across world regions.

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