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ORIGINAL ARTICLE

Association of socioeconomic status with cardiovascular disease and cardiovascular risk factors: a systematic review and meta-analysis

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Abstract

Aim Cardiovascular disease (CVD) remains one of the leading causes of mortality worldwide, and several studies have indicated the association between socioeconomic status (SES) with CVD and cardiovascular risk factors (CVRFs). It is necessary to elucidate the association of SES and CVRFs with CVD.

Subject and methods We searched PubMed, Embase, Web of Science, and the Cochrane Library for publications, using "socioeconomic status," "cardiovascular disease," and corresponding synonyms to obtain literature. The quality of studies was evaluated using the National Institutes of Health Quality Assessment Tool (NIH-QAT). All analyses were performed using Stata V.12.0.

Results There were 31 eligible studies included in this meta-analysis. All studies presented a low risk of bias via NIH-QAT assessment. As for CVD incidence/mortality, pooled hazard ratios (HR) of low and middle vs. high income were [HR = 1.22 (1.17–1.28); HR = 1.12 (1.09-1.16)] and [HR = 1.37 (1.21–1.56); HR = 1.19 (1.06–1.34)]. The HR of education were [HR = 1.44 (1.28–1.63); HR = 1.2 (1.11–1.3)] and [HR = 1.5 (1.22–1.83); HR = 1.13 (1.05–1.22)]. The HR of deprivation were [HR = 1.28 (1.16–1.41); HR = 1.07 (1.03–1.11)] and [HR = 1.19 (1.11–1.29); HR = 1.1 (1.02–1.17)]. SES was negatively correlated with CVD outcomes. A subgroup analysis of gender and national income level also yielded a negative correlation, and additional details were also obtained.

Conclusions SES is inversely correlated with CVD outcomes and the prevalence of CVRFs. As for CVD incidence, women may be more sensitive to income and education. In terms of CVD mortality, men may be more sensitive to income and education, and people from low- and middle-income countries are sensitive to income and education.

Keywords Cardiovascular disease · Cardiovascular risk factors · Socioeconomic status · Meta-analysis

Introduction

Significant advances have recently been achieved in cardiovascular disease (CVD) management, but CVD is still one of the leading causes of death globally. The morbidity and mortality of CVD remain high in both developed and developing countries (Goswami et al. 2021), posing a major burden on global health, society, and finance (Timmis et al. 2022; Townsend et al. 2022). Extensive studies have demonstrated that CVD may be associated with socioeconomic status (SES) and cardiovascular risk factors (CVRFs) (Havranek et al. 2015; Kaplan and Keil 1993; Woodward et al. 2007; Hippisley-Cox et al. 2008). Thus, it is necessary to investigate the association of SES with CVD and CVRFs.

Some previous meta-analyses assessed the relationship between SES and CVD only by exploring limited aspects of CVRFs, such as gender, education, and income(Khaing et al. 2017; Backholer et al. 2017), rather than comprehensively analyzing the underlying association among them. In addition, there is no meta-analysis to systematically analyze the association considering different income levels in different countries. The latest review we retrieved was published in 2018 (Schultz et al. 2018), which is four years ago. Due to the COVID-19 epidemic since 2019, the economies of countries worldwide have been affected to various degrees, resulting in a widening gap between country economies,

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which may present a deviation of previous research results from the current situation. We believe that a meta-analysis is needed to update the results of previous studies and further elucidate the relationship between SES, CVRFs, and CVD, hoping to provide a theoretical basis for the treatment and prevention of CVD in the future.

Methods

This study was carried out based on the Cochrane Handbook for the Systematic Review of Interventions (for details, see http://training.cochrane.org/handbook) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA)(Moher et al. 2009). The research protocol was registered on PROSPERO (ID: CRD42022352904).

Inclusion and exclusion criteria

Research types

The research types included observational cohort and cross-sectional studies.

Research participants

The research participants were enrolled when cases were at (1) age ≥ 18 years old, and (2) had no other major diseases other than CVD.

Intervention measures

(1) The SES indicators of the exposed group were at low or medium levels in the research group. The SES indicators of the observation group were at a high level in the research group. (2) The observation period was longer than or equal to 12 months.

Outcomes and study factors

The outcomes of our study were CVD incidence and mortality. SES, including income, education, and deprivation, was our study factor, which was reported differently across studies.

To standardize data for included studies, if original studies reported SES as quartiles or four groups, the 1st, 2nd+3rd, and 4th quartiles or groups were reclassified into three groups: low, middle, and high, respectively. If studies reported SES as quintiles or five groups, the 1st+2nd, 3rd+4th, and 5th quintiles or groups were reclassified as low, middle, and high, respectively. When a study reported a reference group, which was not the highest SES group, the relevant HR and 95% confidence intervals (CI) were recalculated using the highest one as a reference, utilizing a method developed by Hamling et al. (2008). Based on the income classification by World Bank, we divided the countries selected for our research into low- and middle-income countries (LMICs) and high-income countries (HICs).

Exclusion criteria

(1) SES was not addressed or SES indicators were not stated; (2) Duplicated studies (for overlapping data, the latest published study and/or the one with the largest sample size would be selected); (3) Reviews, conference abstracts, case reports, letters, animal tests, etc.; and (4) Studies published were not written in English.

Search strategy

A researcher systematically searched PubMed, Embase, Web of Science, and the Cochrane Library for publications prior to March 24, 2022, using predefined keywords and Medical Subject Headings (MeSH), including "socioeconomic status," "cardiovascular disease," and their synonyms to obtain relevant literature. Due to the long time spent on data processing, we conducted a complementary search on August 5, 2022, using the same search terms as the above described. Furthermore, potential candidate papers were manually checked in the references of the included studies. This study does not require ethical approval or patient consent. Online Resource 1 outlines the search strategy in detail.

Review for inclusion

Two researchers independently examined the eligibility and screened the titles and abstracts of all identified potential studies. Then, the two researchers continued with a full-text review to finalize the study selection. If there was any disagreements, a common decision was made together with a third researcher.

Data extraction and quality assessment

Data were extracted from each eligible study by two researchers. Any disagreements were resolved through discussion with a third reviewer to ensure the validity of the research results. Extracted data included authors, year of publication, country, sample size, gender, exposed group, observation group, SES indicators, and outcome indicators.

Two researchers independently evaluated the quality of included studies using the National Institutes of Health Quality Assessment Tool (NIH-QAT) (available from https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools), including 14 items, such as "Are the study issues or objectives identified in this article?", etc., and any inconsistencies or disputes were settled by a third reviewer. Each study was assessed as low risk of bias (most criteria met), middle risk of bias (some criteria met), or high risk of bias (few criteria met).

Statistical analysis

Stata 12.0 software was adopted to perform statistical analysis of the included literature, such as the tests for heterogeneity, publication bias analysis, and sensitivity analysis. To compare the highest group with the lowest or middle group of SES, HR, and 95%CI were calculated using a logarithmic transformation. Heterogeneity was determined using the Q statistic and I^2 tests. If $P > 0.1$ and $I^2 \leq 50\%$, the heterogeneity between studies was acceptable, and a fixed effects model was adopted for meta-analysis; If $P \leq 0.1$ or $I^2 > 50\%$, heterogeneity between studies was high, and a random effects model was employed for meta-analysis.

Results

Study selection

Records from all retrieved search results were downloaded and merged with Endnote version X9. A total of 33,745 potentially relevant studies were initially detected through database searches (PubMed n = 2567, Embase n = 18,849, the Cochrane Library n = 487, and Web of Science n = 11,842). After excluding 5248 repeated studies during an initial evaluation, we subsequently excluded 11,501 studies published before 2010. Given the world's economic development and changes in people's living standards, such studies before 2010 may not be suitable for the current situation. Meanwhile, 2872 articles were not written in the English language or did not conform to disease studies, and 8631 articles were reviews, conference abstracts, case reports, letters, and animal tests, which were ruled out. The remaining literature was further screened for titles, abstracts, and full texts, and 5462 studies were excluded. Ultimately, 31 studies published between 2010 and 2022 were included. The literature identification process is demonstrated in Fig. 1.

Study characteristics

A total of 31 studies (Deguen et al. 2010; Gerber et al. 2010; Christensen et al. 2011; Donyavi et al. 2011; Sauvaget et al. 2011; Blais et al. 2012; Koopman et al. 2012; Machón et al. 2012; Masoudkabir et al. 2012; van Oeffelen et al. 2012; Alter et al. 2013; Quan et al. 2013; Coady et al. 2014; Wang et al. 2014; Thorne et al. 2015; Floud et al. 2016; Kilpi et al. 2016; Colantonio et al. 2017; Kilpi et al. 2017; Cho et al. 2019; Geyer et al. 2019; Kjærulff et al. 2019; Kriegbaum et al. 2019; Rosengren et al. 2019; An et al. 2020) were included, and the studies on HICs were in the majority, while few studies focused on LMICs. Each study had a large sample size, and all analyzed both women and men with one exception, which only focused on the factors related to women. Through a comprehensive assessment of the included studies, SES indicators, including income, education, and deprivation index, were determined. The summary of the basic characteristics of the included studies is presented in Table 1.

Results of the quality assessment

Based on the NIH-QAT checklist, all included studies presented a low risk of bias. The least frequently reported item in the included studies was "item 13." "Item 10" and "item 12" were not applicable. Further information about the risk of bias assessment is described in Online Resource 2.

The results of meta-analysis

A meta-analysis was conducted to investigate the relationship between SES and CVD outcomes through the aspects of income, education, and deprivation. More detailed information is presented in Online Resource 3.

Income and CVD outcomes

Twenty-one studies (Sauvaget et al. 2011; Koopman et al. 2012; Masoudkabir et al. 2012; van Oeffelen et al. 2012; Alter et al. 2013; Quan et al. 2013; Coady et al. 2014; Wang et al. 2014; Kilpi et al. 2016, 2017; Cho et al. 2019; Geyer et al. 2019; An et al. 2020) assessed the effects of income on CVD outcomes. A random-effects model ($I^2 = 75.3\%$, $P = 0.000$; $I^2 = 92.7\%$, $P = 0.000$) was adopted to combine the effect sizes, and the analysis results revealed that the risk of CVD incidence in low- and middle-income groups was 22% and 12% higher than that in the high-income group, respectively [HR = 1.22, 95%CI (1.17, 1.28); HR = 1.12, 95%CI (1.09, 1.16)]. Meanwhile, the risk of CVD mortality in low- and middle-income groups was 37% and 19% higher than that in the high-income group, respectively [HR=1.37, 95%CI (1.21, 1.56); HR = 1.19, 95%CI (1.06, 1.34)]. The effects of income on CVD incidence and mortality are shown in Fig. 2.

Education and CVD outcomes

Ten studies (Christensen et al. 2011; Donyavi et al. 2011; Masoudkabir et al. 2012; Floud et al. 2016; Kilpi et al. 2016, 2017; Kriegbaum et al. 2019; Rosengren et al. 2019; Hassen et al. 2020; Ge et al. 2022) assessed the

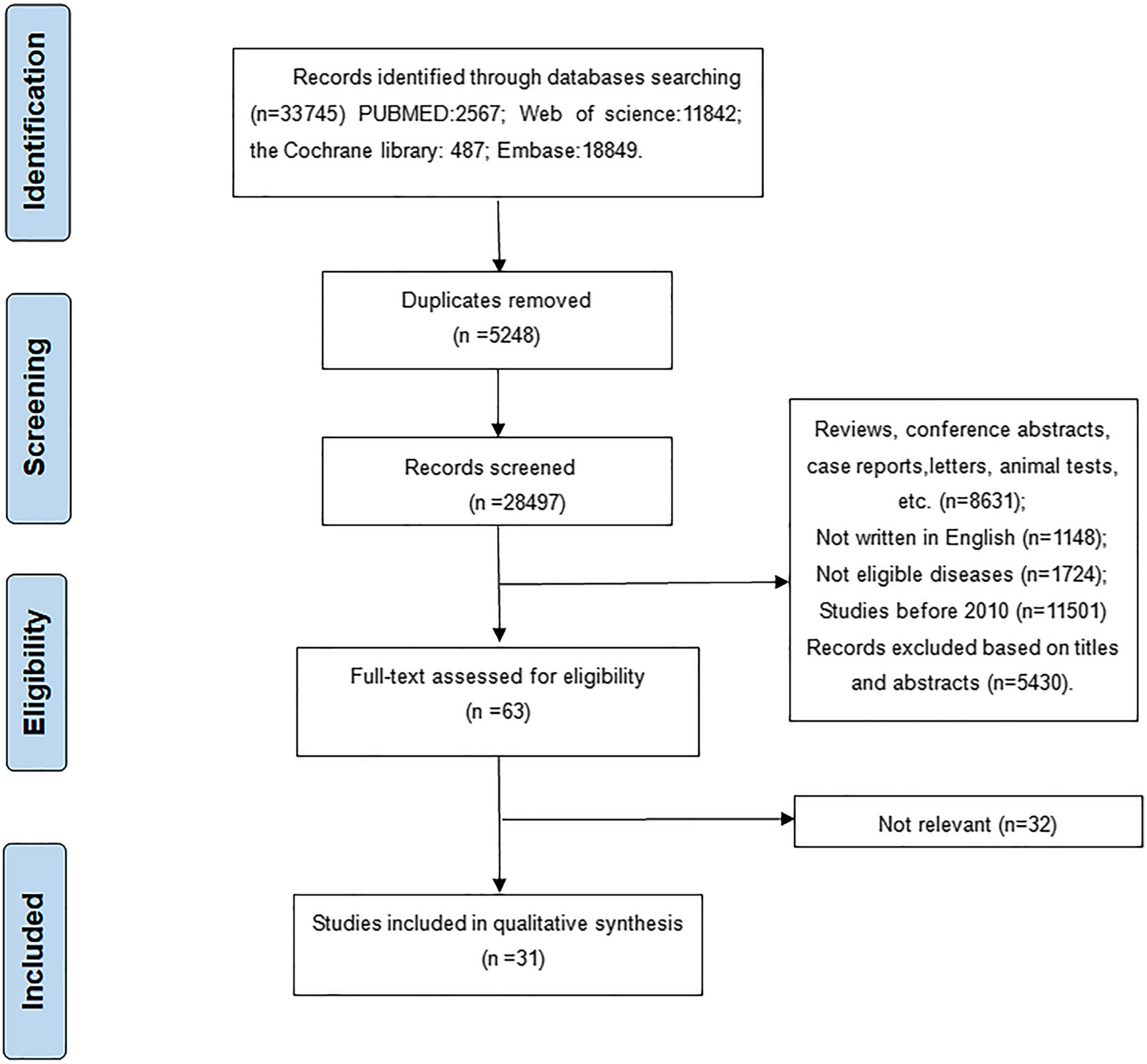

Fig. 1 Flow chart of study inclusion identification

effects of education on CVD outcomes. A random-effects model (I^2 = 82.8%, P = 0.000; I^2 = 67.8%, P = 0.003) was adopted to combine the effect sizes, and the analysis results revealed that the risk of CVD incidence in low- and middle-education groups was 44% and 20% higher than that in the high-education group, respectively [HR = 1.44, 95%CI (1.28, 1.63); HR = 1.20, 95%CI (1.11, 1.30)]. In addition, the risk of CVD mortality in low- and middle-education groups was 50% and 13% higher than that in the high-education group, respectively [HR = 1.50, 95%CI (1.22, 1.83); HR = 1.13, 95%CI (1.05, 1.22)]. The effects of education on CVD incidence and mortality are shown in Fig. 3.

Deprivation and CVD outcomes

Eight studies (Deguen et al. 2010; Gerber et al. 2010; Blais et al. 2012; Machón et al. 2012; Thorne et al. 2015; Floud et al. 2016; Colantonio et al. 2017; Jin et al. 2021) assessed the effects of deprivation on CVD outcomes. To facilitate the analysis and comparison of other SES indicators, the low group was considered to have the highest deprivation index, that is, the lowest SES. The high group was regarded as having the lowest deprivation index, that is, the highest SES. A random-effects model (I^2 = 55.0%, P = 0.049; I^2 = 69.7%, P = 0.000) was adopted to combine the effect sizes, and the analysis results revealed that the risk of CVD incidence in

Table 1 Study characteristics

Author (year)	Country	Total sample size	Gender	Exposure group	Observation group	SES* indicators	Outcome indicators
Wang et al. (2014)	China	23568	Both	Low Middle	High	Income	Mortality
Van Oeffelen et al.(2012)	Holland	76351	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Income	Mortality
Koopman et al. (2012)	Holland	317564	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Income	Incidence
Tetzlaff et al. (2021)	German	1253083	Both	Low Middle	High	Income	Incidence and mortality
Geyer et al. (2019)	German	18390577	Both	Low Middle	High	Income	Incidence and mortality
Sung et al. (2020)	Korea	178812	Both	Low Middle	High	Income	Mortality
Hassen et al. (2020)	Belgium, France	14322	Both	Low Middle	High	Income	Incidence
				Low Middle	High	Education	
Coady et al. (2014)	Ameirica	15972	Both	Quintile 1 Quintile 2 Quintile 3 Quintile 4	Quintile 5	Income	Mortality
Cho et al.(2019)	Korea	2705090	Both	Low Middle	High	Income	Incidence
Alter et al.(2013)	Canada	1368	Both	Low Middle	High	Income	Mortality
Rosengren et al. (2019)	America, China, Tanzania and other 17 countries	154169	Both	Poorest third Middle third	Richest third	Income	Incidence and mortality
				None or primary only; Secondary	Trade school, college, oruniversity	Education	
Masoudkabir et al.(2012)	Iran	6504	Both	1st tertile 2nd tertile	3rd tertile	Income	Incidence
				0–5 years 6–12 years	>12 years	Education	
Quan et al.(2013)	Canada	3531089	Both	Quintile 1 Quintile 2 Quintile 3 Quintile 4	Quintile 5	Income	Incidence
An et al.(2020)	Ameirica	77101	Both	$0–$34.9k; $35k–$49.9k; $50–$64.9k; $65k–$79.9k;	≥$80k	Income	Incidence
Machado et al. (2021)	Ameirica	5579	Both	Quintile 1 Quintile 2 Quintile 3 Quintile 4	Quintile 5	Income	Incidence
Kjærulff et al. (2019)	Denmark	95274	Both	Low Middle	High	Income	Mortality
Sauvaget et al. (2011)	India	167331	Both	<₹1500; ₹1500-₹3000; ₹3001-₹5000;	>₹5000	Income	Mortality
Christensen et al. (2011)	Denmark	18486	Both	<8 years; 8-10 years	>10 years	Education	Incidence

Table 1 (continued)

Author (year)	Country	Total sample size	Gender	Exposure group	Observation group	SES* indicators	Outcome indicators
Ge et al.(2022)	China	4725	Both	Low Middle	High	Income	Mortality
				Low Middle	High	Education	
Donyavi et al. (2011)	Iran	1283	Both	Illiterate; 1-5 years; 6-9 years; 10-12 years;	> 12 years	Education	Mortality
Kilpi et al.(2017)	Finland	94501	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Income	Incidence
				Basic Secondary	Tertiary	Education	
Kriegbaum et al. (2019)	Denmark	1235142	Both	Quartile 1 Quartile 2 Quartile 3	Quartile 4	Income	Incidence
				1st tertile 2nd tertile	3rd tertile	Education	
Kilpi et al.(2016)	Finland	302885	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Income	Incidence and mortality
				Basic; Secondary; Lowest tertiary;	Higher and lower tertiary	Education	
Floud et al. (2016)	UK	1202983	Bemale	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Deprivation index	Incidence and mortality
				< Compulsory-schooling; Compulsoryschool-ing; Technical; Second-ary	Tertiary	Education	
Deguen et al. (2010)	France	1193	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Deprivation index	Incidence
Colantonio et al. (2017)	Ameirica	9066	Both	Quartile 4 Quartile 3 Quartile 2	Quartile 1	Deprivation index	Incidence
Jin et al.(2021)	Scotland	217965	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Deprivation index	Mortality
Thorne et al. (2015)	UK	30663	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Deprivation index	Mortality
Machón et al. (2012)	Spain	3974	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Deprivation index	Mortality

Table 1 (continued)

Author (year)	Country	Total sample size	Gender	Exposure group	Observation group	SES* indicators	Outcome indicators
Blais et al.(2012)	Canada	53130	Both	Quintile 5 Quintile 4 Quintile 3 Quintile 2	Quintile 1	Deprivation index	Mortality
Gerber et al. (2010)	Israel	1179	Both	Low Middle	High	Deprivation index	Mortality

*SES, socioeconomic status

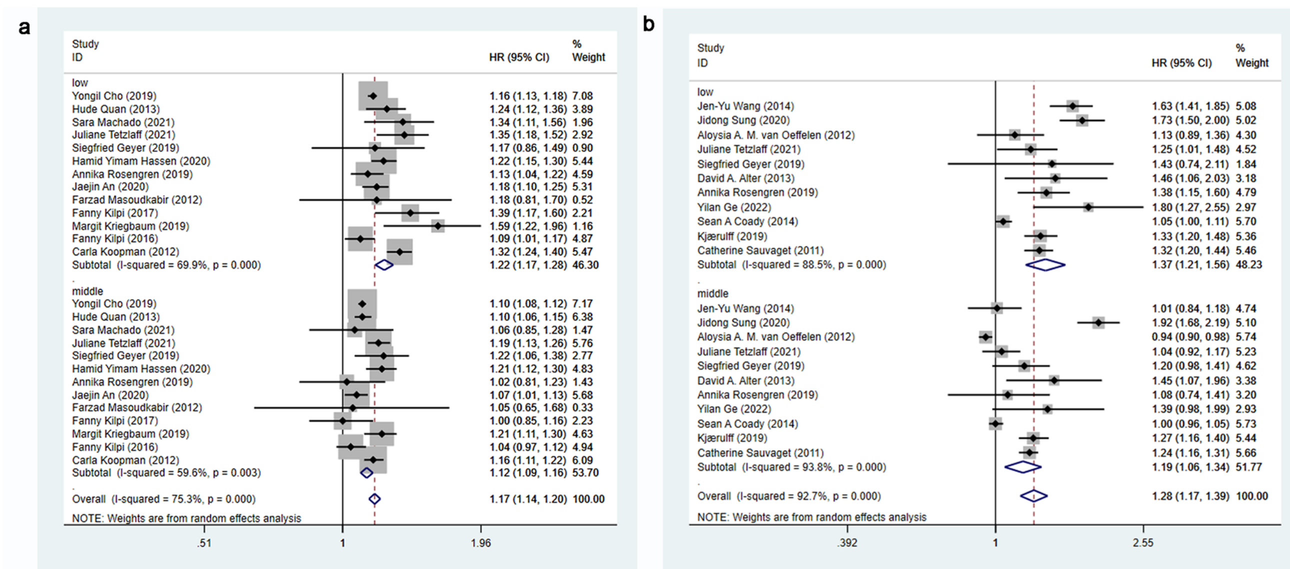

Fig. 2 (**a**) Effects of income on CVD incidence (**b**) Effects of income on CVD mortality

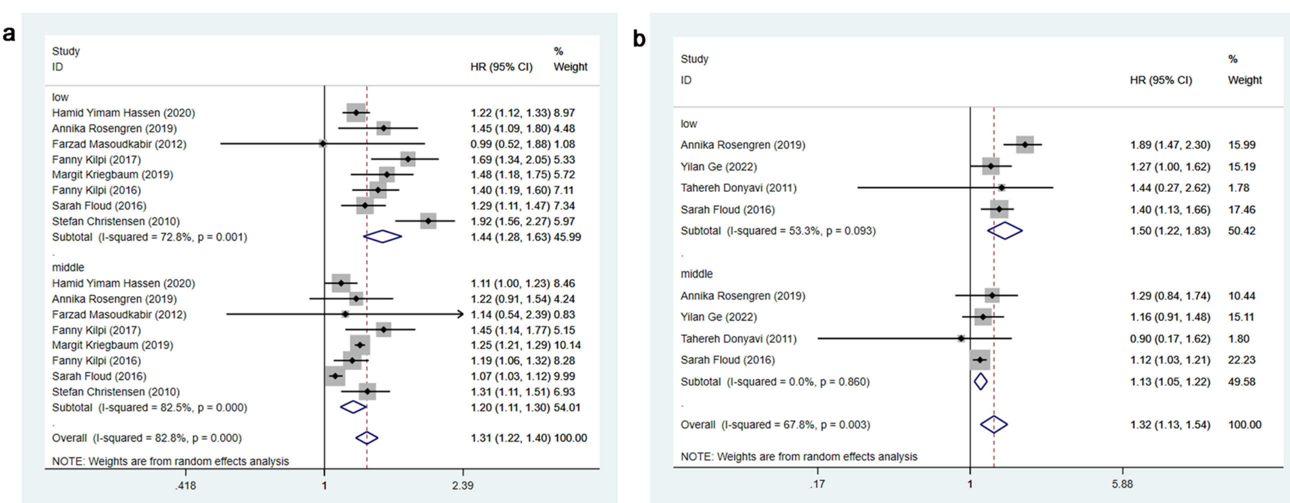

Fig. 3 (**a**) Effects of education on CVD incidence (**b**) Effects of education on CVD mortality

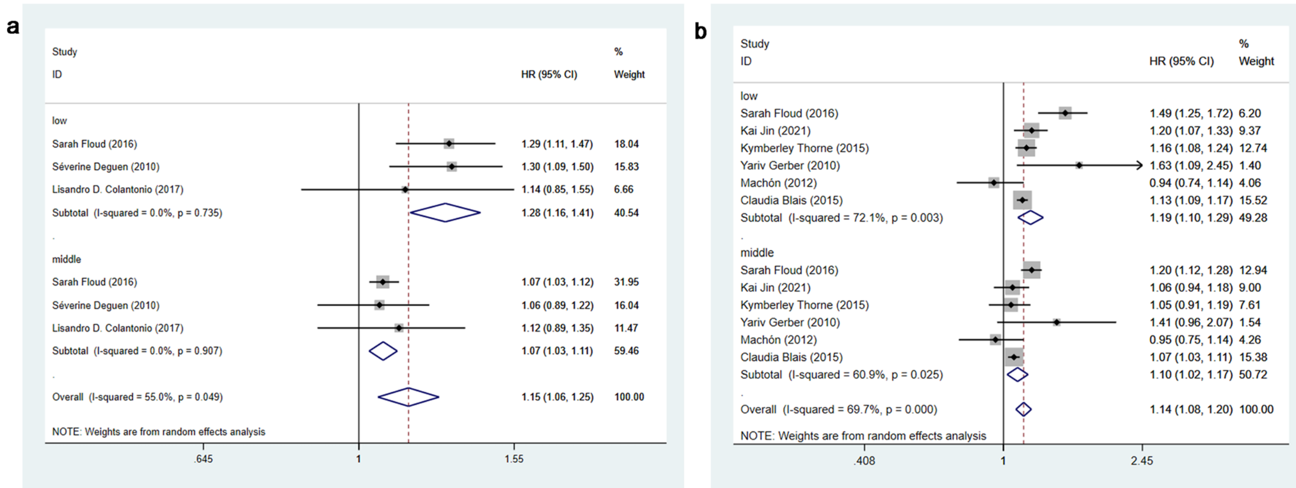

Fig. 4 (**a**) Effects of deprivation on CVD incidence (**b**) Effects of deprivation on CVD mortality

low and middle groups was 28% and 7% higher than that in the high group, respectively [HR = 1.28, 95%CI (1.16, 1.41); HR = 1.07, 95%CI (1.03, 1.11)]. Meanwhile, the risk of CVD mortality in low and middle groups was 19% and 10% higher than that in the high group, respectively [HR = 1.19, 95%CI (1.11, 1.29); HR = 1.10, 95%CI (1.02, 1.17)]. The effects of deprivation on CVD incidence and mortality are shown in Fig. 4.

Subgroup analysis

We conducted subgroup analyses on gender and national income levels to explore more details. The detailed information is presented in Online Resource 3.

Male/female income and CVD outcomes

Nine studies (Koopman et al. 2012; van Oeffelen et al. 2012; Coady et al. 2014; Wang et al. 2014; Kilpi et al. 2016, 2017; Geyer et al. 2019; Kriegbaum et al. 2019; Tetzlaff et al. 2021) evaluated the relationship between male/female income and CVD outcomes. A random-effects model (I^2 = 88.8%, P = 0.000; I^2 = 93.6%, P = 0.000; I^2 = 96.2%, P = 0.000; I^2 = 79.1%, P = 0.000) was adopted to combine the effect sizes, and the analysis results revealed that the risk of CVD incidence in low- and middle-income men was 29% and 14% higher than that in high-income men, respectively [HR = 1.29, 95%CI (1.17, 1.44); HR = 1.14, 95%CI (1.06, 1.22)]. The risk of CVD incidence in low- and middle-income women was 37% and 18% higher than that in high-income women, respectively [HR = 1.37, 95%CI (1.12, 1.68); HR = 1.18, 95%CI (1.13, 1.24)]. In addition, the risk of CVD mortality in low-income men was 38% higher than that in high-income men [HR = 1.38, 95%CI (1.08, 1.76)]. The risk of CVD mortality in low-income women was 14% higher than that in high-income women [HR = 1.14, 95%CI (1.02, 1.27)]. The difference was not statistically significant in the risk of CVD mortality between middle- and high-income men/women, as shown in Figs. 5 and 6.

LMICs/HICs income and CVD outcomes

Twenty-one studies (Sauvaget et al. 2011; Koopman et al. 2012; Masoudkabir et al. 2012; van Oeffelen et al. 2012; Alter et al. 2013; Quan et al. 2013; Coady et al. 2014; Wang et al. 2014; Kilpi et al. 2016, 2017; Cho et al. 2019; Geyer et al. 2019; An et al. 2020) evaluated the association between income and CVD outcomes among LMICs/HICs. A fixed-effects model (I^2 = 13.7%, P = 0.327) and a random-effects model (I^2 = 78.9%, P = 0.000; I^2 = 69.6%, P = 0.001; I^2 = 92.8%, P = 0.000) were adopted to merge the effect sizes, and the results revealed that the risk of CVD incidence was 14% higher in the low-income group than in the high-income group among LMICs [HR = 1.14, 95%CI (1.04, 1.24)]. The risk of CVD incidence was 23% and 12% higher in low- and middle-income groups than in the high-income group among HICs, respectively [HR = 1.23, 95%CI (1.18, 1.29); HR = 1.12, 95%CI (1.08, 1.16)]. In addition, the risk of CVD mortality was 45% and 18% higher in low- and middle-income groups than in the high-income group among LMICs, respectively [HR = 1.45, 95%CI (1.28, 1.64); HR = 1.18, 95%CI (1.06, 1.32)]. The risk of CVD mortality was 33% and 18% higher in low- and middle-income groups than in high-income group among HICs, respectively [HR = 1.33, 95%CI (1.13, 1.57); HR = 1.18, 95%CI (1.02, 1.37)]. There was no significant difference in the risk of CVD incidence between the middle- and high-income groups among

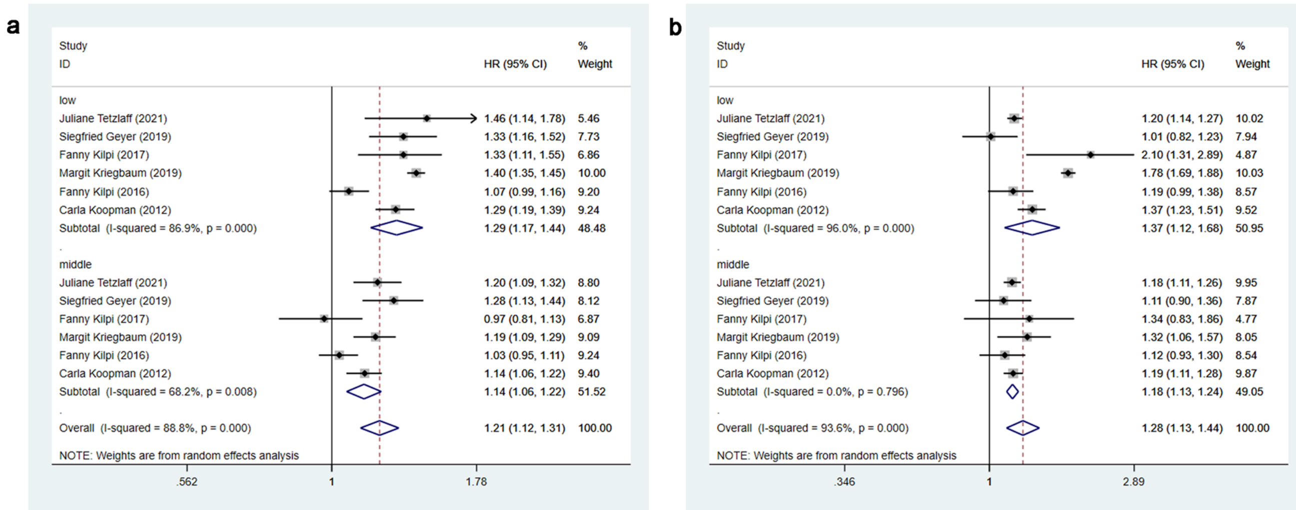

Fig. 5 (**a**) Effects of male income on CVD incidence (**b**) Effects of female income on CVD incidence

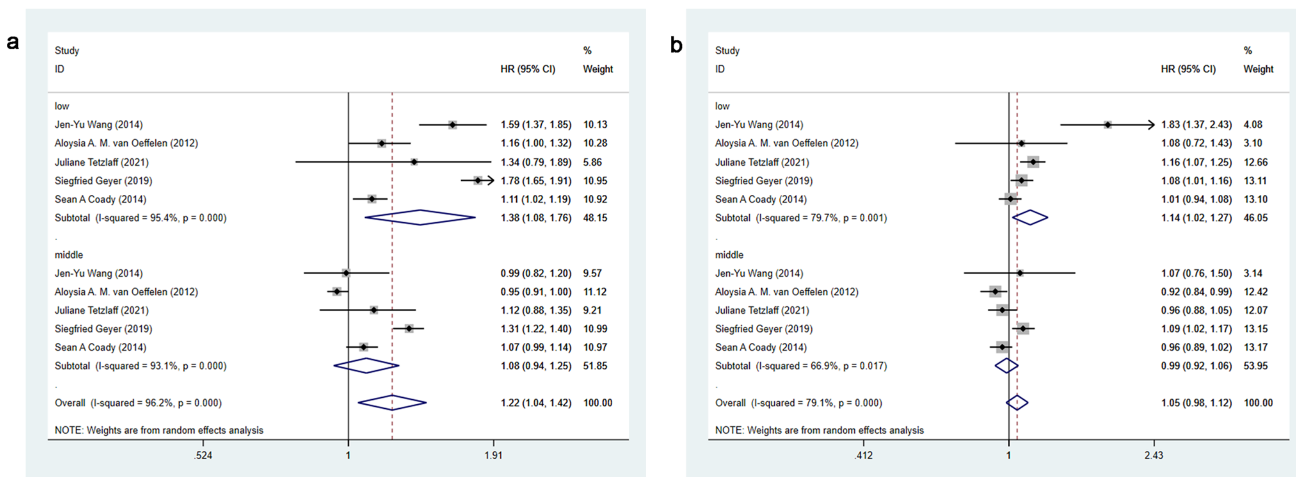

Fig. 6 (**a**) Effects of male income on CVD mortality (**b**) Effects of female income on CVD mortality

LMICs. The effects of income on CVD incidence among LMICs/HICs are shown in Fig. 7, and the effects of income on CVD mortality among LMICs/HICs are shown in Fig. 8.

Male/female education and CVD outcomes

Four studies (Christensen et al. 2011; Kilpi et al. 2016, 2017; Kriegbaum et al. 2019) evaluated the relationship between male/female education and CVD incidence. Due to a lack of relevant literature, it was impossible to analyze the relationship between male/female education and CVD mortality. A random-effects model ($I^2 = 71.0\%$, $P = 0.001$; $I^2 = 85.2\%$, $P = 0.000$) was adopted to merge the effect sizes, and the analysis results revealed that the risk of CVD incidence in low- and middle-education men was 51% and 25% higher than that in high-education men, respectively [HR = 1.51, 95%CI (1.29, 1.76); HR = 1.25, 95%CI (1.20, 1.29)]. The risk of CVD incidence in low- and middle-education women was 67% and 26% higher than that in high-education women, respectively [HR = 1.67, 95%CI (1.42, 1.97); HR = 1.26, 95%CI (1.09, 1.46)]. The effects of male/female education on CVD incidence are shown in Fig. 9.

LMICs/HICs education and CVD outcomes

Ten studies (Christensen et al. 2011; Donyavi et al. 2011; Masoudkabir et al. 2012; Floud et al. 2016; Kilpi et al. 2016, 2017; Kriegbaum et al. 2019; Rosengren et al. 2019; Hassen et al. 2020; Ge et al. 2022) evaluated the association between education and CVD outcomes among LMICs/HICs. A random-effects model ($I^2 = 77.6\%$, $P = 0.000$; $I^2 = 85.4\%$, $P = 0.000$; $I^2 = 53.7\%$, $P= 0.035$; $I^2 = 60.4\%$, $P =$

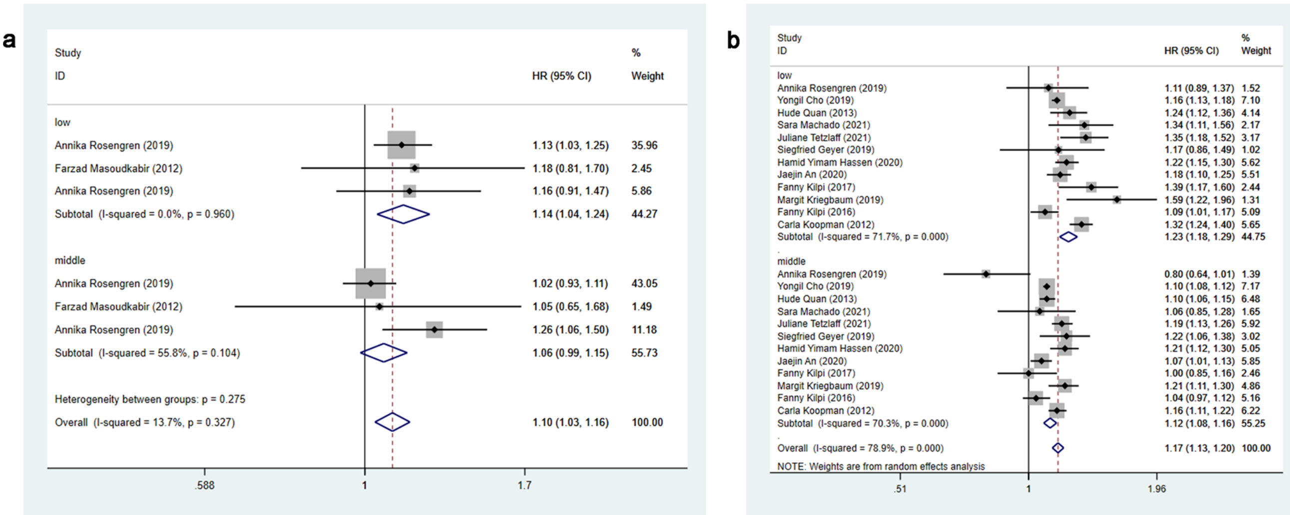

Fig. 7 (**a**) Effects of income on CVD incidence among LMICs (**b**) Effects of income on CVD incidence among HICs

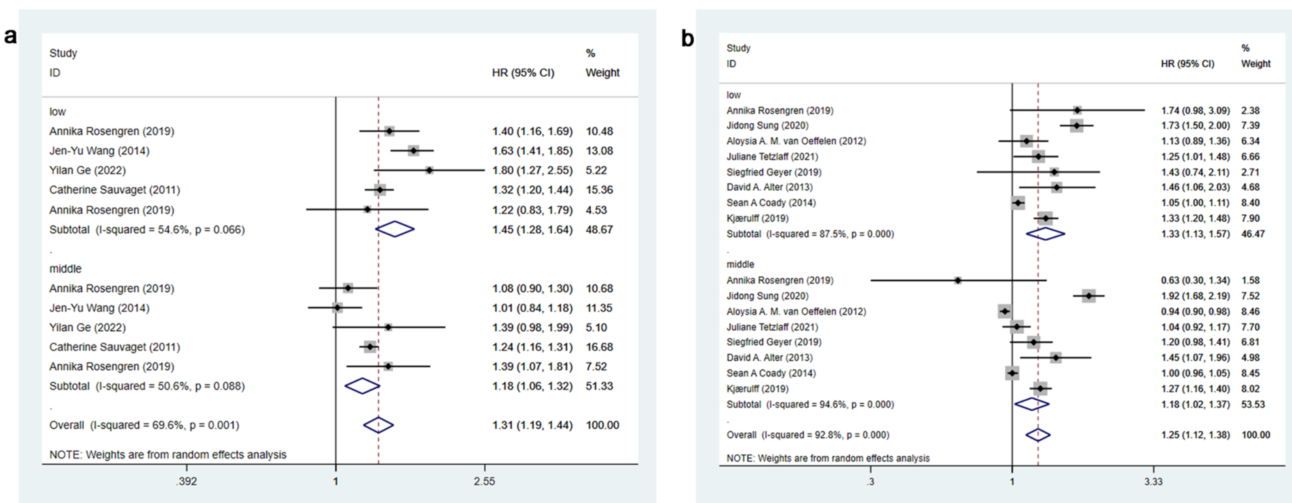

Fig. 8 (**a**) Effects of income on CVD mortality among LMICs (**b**) Effects of income on CVD mortality among HICs

0.056) was adopted to merge the effect sizes, and the analysis revealed that the risk of CVD incidence was 52% higher in the low-education group than that in the high-education group among LMICs [HR = 1.52, 95%CI (1.09, 2.11)]. The risk of CVD incidence was 43% and 18% higher in low- and middle-education groups than in the high-education group among HICs, respectively [HR = 1.43, 95%CI (1.25, 1.62); HR = 1.18, 95%CI (1.08, 1.28)]. In addition, the risk of CVD mortality was 66% and 32% higher in low- and middle-education groups than in the high-education group among LMICs, respectively [HR = 1.66, 95%CI (1.24, 2.21); HR = 1.32, 95%CI (1.04, 1.67)]. The risk of CVD mortality was 44% and 12% higher in low- and middle-education groups than in the high-education group among HICs, respectively [HR = 1.44, 95%CI (1.19, 1.75); HR = 1.12, 95%CI (1.03, 1.21)]. There was no significant difference in the risk of CVD incidence between the middle and high-education groups in middle-income countries. The effects of education on CVD incidence among LMICs/HICs are shown in Fig. 10, and the effects of education on CVD mortality among LMICs/HICs are shown in Fig. 11.

Publication bias and sensitivity analysis

Based on the SES indicators of the included studies, the publication bias was analyzed using funnel plots and Egger's tests. The value of $P > 0.05$ was considered to have no publication bias. Egger's tests revealed that the P values of

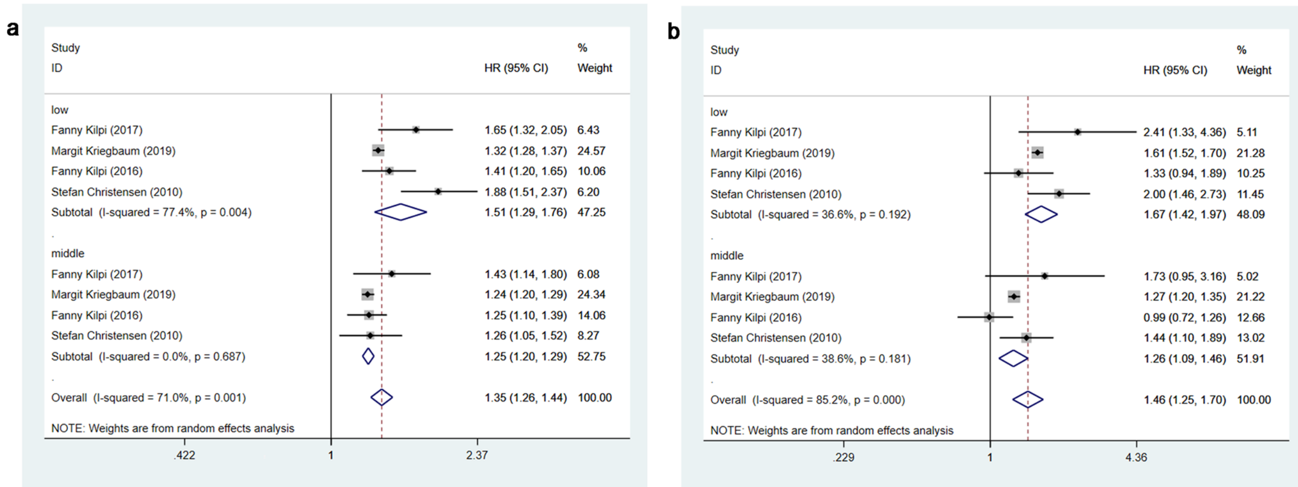

Fig. 9 (**a**) Effects of male education on CVD incidence (**b**) Effects of female education on CVD incidence

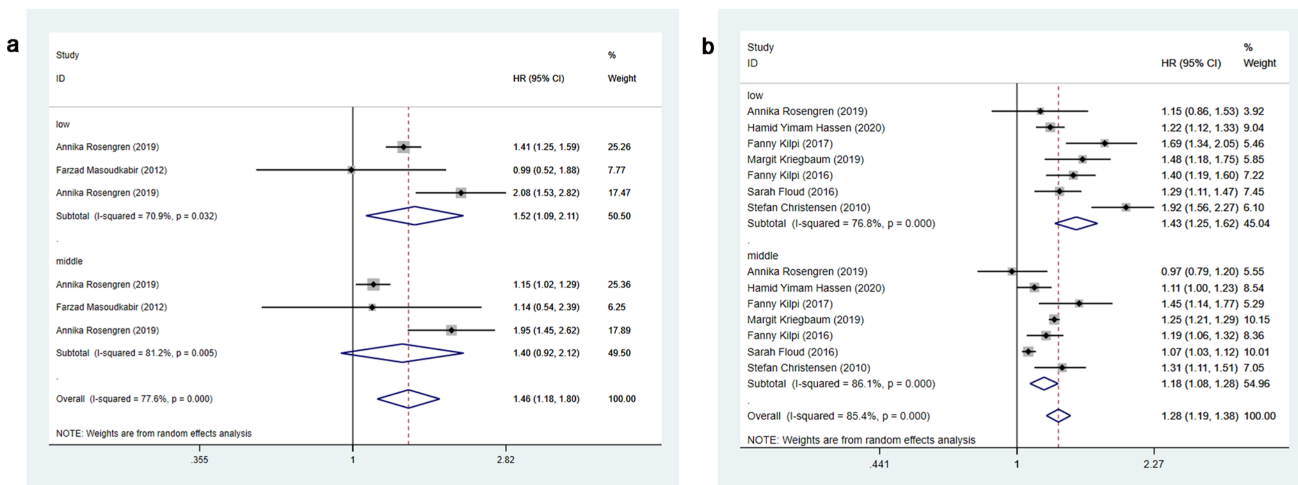

Fig. 10 (**a**) Effects of education on CVD incidence among LMICs (**b**) Effects of education on CVD incidence among HICs

"Income of CVD Mortality" and "Income in HICs of CVD Mortality" were 0.003 and 0.017, respectively (as shown in Online Resource 4). Thus, the presence of publication bias among studies was considered. The indicators of publication bias in both groups were further analyzed using the trim-and-fill method (shown in Online Resource 5). After adding ten studies to the model, the funnel plot was symmetric, and the combined effect size of the "Income of CVD mortality" group was 1.08, 95%CI (0.99, 1.18). Similarly, after the addition of six studies, the combined effect size of the "Income in HICs of CVD mortality" group was 1.07, 95%CI (0.96, 1.19). Sensitivity analyses were performed by excluding each study individually from the meta-analysis to rule out the overrepresentation of individual study results in the meta-analysis. Sensitivity analyses revealed that the results of the meta-analysis were stable and reliable.

Discussion

The present study indicated that the incidence and mortality of CVD were higher in the lower SES population as compared to the higher SES population, that is, SES was inversely associated with CVD outcomes. This is due to the high prevalence of CVRFs such as smoking, alcohol consumption, hypertension, physical inactivity, obesity, diabetes, an unhealthy diet, and depression in low-SES groups, as well as the likelihood of delayed or lack of CVD care and treatment, which is consistent with previous

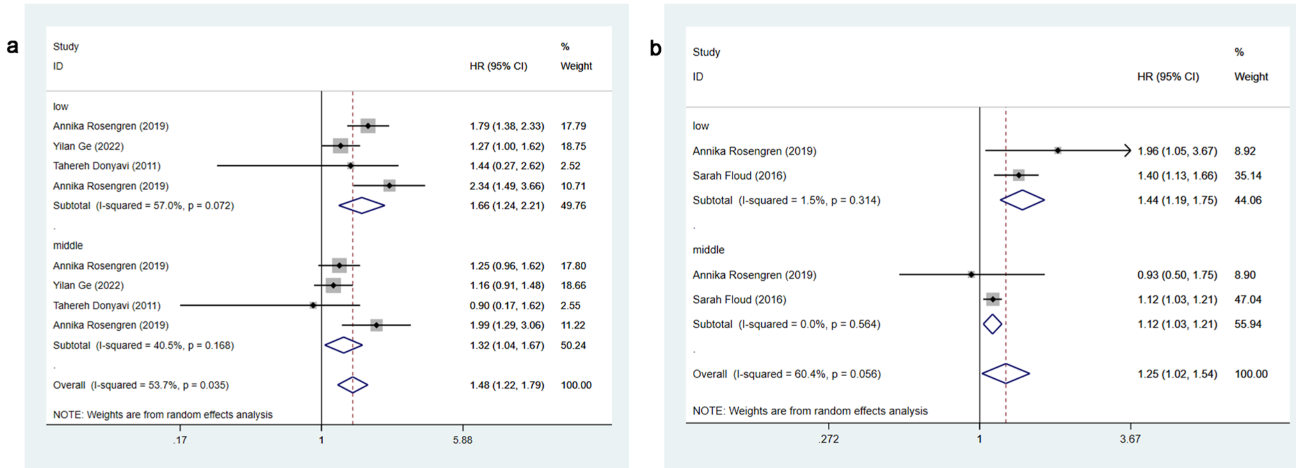

Fig. 11 (**a**) Effects of education on CVD mortality among LMICs (**b**) Effects of education on CVD mortality among HICs

studies (Khaing et al. 2017; Backholer et al. 2017). Gerber et al. (2010) have also noted that groups with higher SES give more priority to health and health-related behaviors (e.g., smoking cessation, a healthy diet, and physical activity) and maintain closer social ties (e.g., social cohesion and support), which may minimize CVD risk. Groups with lower SES may endure additional pressures of anxiety and stress (e.g., crime and unemployment), which may further exacerbate CVD risk.

Additionally, higher education and income are associated with higher acceptance and compliance with CVD treatment, and higher availability and affordability of CVD management and care. Patients with higher education and income tend to have easier access to and accept more timely treatment and care services, thereby reducing the risk of CVD (Gerber et al. 2011; Rabi et al. 2010; Abdalla et al. 2020; Pietrzykowski et al. 2020; Bandi et al. 2017; Alter et al. 1999). Differing from income and education, deprivation affects CVD mainly through CVRFs. The more severe the deprivation is, the higher the CVRFs prevalence is, which may indirectly affect CVD incidence (Pujades-Rodriguez et al. 2014; Foster et al. 2018).

We conducted a subgroup analysis by gender. In addition to the previously addressed results that SES was negatively correlated with CVD outcomes, we also discovered that women tend to be more sensitive to income and education in terms of CVD incidence. This may be attributed to lower risk awareness in women with less typical clinical symptoms, who are less likely to receive preventive CVD treatment (Mehta et al. 2016; Grintsova et al. 2014; Giles et al. 1993). CVD mortality is the opposite, and men tend to be more sensitive to income and education, possibly because they are more likely to develop comorbidities and have a delay in seeking medical care (Miettinen et al. 1998; Salomaa et al. 2001), resulting in exacerbation of the disease.

We also conducted a subgroup analysis by national income levels, and the negative correlation between SES and CVD outcomes was also found in both LMICs and HICs. Moreover, in terms of CVD mortality, the LMIC population tends to be more sensitive to income and education. This may be attributed to differences between LMICs and HICs in terms of medical services, access to and affordability of medicines, and thresholds for diagnosis and treatment (Yusuf et al. 2014). Furthermore, HICs are more successful in risk identification and disease control (Pujades-Rodriguez et al. 2014; Neuhauser et al. 2015), whereas LMICs do poorly in risk identification and disease prevention (Ikeda et al. 2014; Farzadfar et al. 2011), which may be another cause for the described trend.

In addition, some studies have indicated a positive correlation between SES and CVD outcomes in LMICs (Stringhini and Bovet 2017; Terris 1999; Chadha et al. 1990), which seems inconsistent with our research. However, this difference is explicable, which may be because the LMICs included in our study are experiencing a transition from a positive correlation to a negative correlation between SES and CVD (Clark et al. 2009). In the early stage of economic development, people with high SES may have a higher risk of CVD. While in the later stage, low SES can be associated with a higher risk of CVD (Liu et al. 2013; Chaix et al. 2007; Kapral et al. 2012; Yusuf et al. 2001), that is, the relationship between SES and CVD in LMICs may eventually be negatively correlated with HICs.

The current study performed a comprehensive analysis of the association between gender, national income levels, SES, and CVD, and it also investigated the interrelationship between SES and CVD with more detailed findings, which are considered one of the highlights of this research. To our knowledge, this is the first meta-analysis to systematically assess the association between SES and CVD outcomes based on different national income levels in different countries. Additionally, to improve the comparability and explore the effect of the risk gradient among various studies, we categorized SES into low, medium, and high levels, and further findings were uncovered in terms of gender (Backholer et al. 2017).

This study also has some limitations. First, the pooled results presented certain heterogeneity, which may be due to the differences in the characteristics of the research population, the definition and classification of SES, and the actual development of HICs and LMICs. Some original data was not available to us, and several studies did not adjust for or report confounding variables. Despite many efforts that have been made to explore heterogeneity, we failed to identify the source of heterogeneity. Second, there are few studies on LMICs after 2010, most of which are from middle-income countries with rapid economic development, including China and India. The interrelationship between SES and CVD in such countries indicates a reverse relationship similar to that of HICs, which is also the reason why our research results are inconsistent with previous results among LMICs. Subsequently, more studies are recommended to focus on LMICs with poor economic conditions.

Conclusions

SES is inversely correlated with CVD outcomes and the prevalence of CVRFs. As for CVD incidence, women tend to be more sensitive to income and education. In terms of CVD mortality, men tend to be more sensitive to income and education, and people from LMICs are sensitive to income and education. Due to the small amount of relevant literature, future research is recommended to highlight the subgroup analysis of gender and LMICs.

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Data availability The data used to support the findings of this study are included within the article.

Code availability Not applicable.

Declarations

Ethical statement Not applicable

Ethics approval Not applicable

Consent to participate Not applicable

Consent for publication Not applicable.

Conflicts of interest The authors declare no competing interests.

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