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Cardiovascular Mortality of 40–70-year-olds in Sri Lanka from 1980 - 2010; an age-period-cohort analysis

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Abstract

Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally; in Sri Lanka which has a rapidly ageing population, CVDs contribute to over 34% of deaths and is increasing. The objective of this study was to compare cardiovascular mortality of 40–70-year-old Sri Lankans from 1980-2010 by age, birth cohorts and sex.

Methods

A comparative retrospective study was done using secondary data of cardiovascular deaths due to ischemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD) among 40-70-year-old Sri Lankans from 1980-2010. Data were extracted from the WHO mortality database. Population data were extracted from UN database. The comparison of mortality data was done by age, birth cohort and by sex.

Results

Mortality due to IHD increased with age but decreased with birth cohorts with time (range 3.7-390 per 100,000 population); there was a spike in the IHD mortality rates in both age-groups and birth cohorts in 2000. Deaths due to HTN markedly increased after 55 years; however, mortality decreased in the younger cohorts (range 2.8-204.81 per 100,000 population). CeVD mortality linearly increased with age (range 3.3-153.3 per 100,000 population); birth cohorts of 1926-1930 and 1931-1935 had a spike in mortality among 60-64 and 65-69 age groups, respectively. Changes were seen among both males and females; mortality rates were higher in males than in females.

Conclusions: All cardiovascular mortality rates increase with age and are higher in males than in females. Age specific cardiovascular mortality rates are lower in the younger birth cohorts as compared to the older birth cohorts. The increase in cardiovascular deaths in Sri Lanka is due to the ageing population. Though the mortality rates are decreasing, the number of cardiovascular events will increase due to the ageing population.

Keywords: Cardiovascular mortality, 1980-2010, 40-70-year-olds, Sri Lanka

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

What is already known in this topic

- Cardiovascular diseases (CVDs) are the leading cause of death globally. WHO estimated that there were 17.9 million deaths due to CVDs accounting for 32% of all global deaths in 2019.
- Various studies across multiple countries have shown a relationship between cardiovascular disease mortality and age periods, indicating that mortality rates vary significantly with different age groups and time periods, influenced by both early life exposures and concurrent changes in risk factors.
- The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher than that observed in many high-income countries

What this study adds

- Despite increase in mortality due to cardiovascular diseases with time, we have shown that mortality rates due to cardiovascular diseases is decreasing with time, age and birth cohorts.
- The results of this study can be used to project mortality rates due to cardiovascular diseases in Sri Lanka.

How this study might affect research, practice or policy

- Although the mortality rates due to cardiovascular diseases are decreasing, the burden of cardiovascular diseases will still be high with the increase in the number of events, both fatal and non-fatal due to the ageing population. This will have implications in the future on providing preventive, curative and rehabilitative healthcare services.

Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally. They comprise a group of diseases of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular disease (CeVD), peripheral artery disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis and pulmonary embolism.[1]

In 2019, it was estimated that there were 17.9 million deaths due to CVDs accounting for 32% of all global deaths; of these deaths, 85% were due to heart attack and stroke. More than 75% of all CVD deaths occur in low- and middle-income countries; CVD deaths comprised 38% of premature deaths (under the age of 70) due to non-communicable diseases. [1]

Hypertension is a leading risk factor for cardiovascular disease with a heavy public health burden worldwide. [2] It is defined as having a blood pressure above 140/90; poorly controlled or uncontrolled blood pressure increases the risk of hypertensive disease (HTN) giving rise to microscopic and macroscopic cardiac remodeling and functional alterations.[3] It is estimated that 1.28 billion adults aged 30–79 years worldwide have hypertension with two-thirds living in low- and middle-income countries.[4] 46% of hypertensives are unaware they have the condition and less than 42% are diagnosed and treated; only 21% of adults with hypertension have it controlled.[4] It is a major cause of premature death worldwide.[4]

The number of CVD deaths has been increasing over time; in 2000, around 14 million people died from cardiovascular diseases globally, while in 2019, close to 18 million died.[5] It was estimated that CVDs would account for >23 million deaths by 2030.[6] Almost all countries experienced a significant decline in mortality from 1990 to 2017.[7] The global mean trend of CVD incidence increased from 1990 to 1996 followed by a decline since then.[7] The decline in

incidence and mortality rates for developed countries was significantly higher than that for developing countries from 1990–2017 ($p < 0.05$); developing nations had a less-steeper decline.[7]

As for all non-communicable diseases, risk factors for cardiovascular diseases include age, sex and other modifiable lifestyle risk factors.[7] The rising death toll is largely due to a growing and ageing global population. Death rates have been declining due to implementation of preventive programmes; large declines in smoking, improvements in screening, diagnosis, and monitoring; and advances in medical treatments, public health initiatives, emergency care, and surgical procedures have all helped to reduce the impact of cardiovascular diseases on people's lives.[7] The large disparities that still exist can be further reduced.

South Asia has a disproportionately high burden of cardiovascular disease, with higher rates of CVD incidence, mortality, and risk factor prevalences than many other regions.[8] Cardiovascular diseases account for 3.9 million deaths in the WHO South-East Asia Region every year, comprising a quarter of all deaths from non-communicable diseases (NCDs), with most of them being preventable.[9] Global research studies related to healthcare have shown that even though South Asians comprise only 25% of the world's population, they account for more than 50% of the world's cardiovascular deaths.[8]

Sri Lanka, a country having one of the fastest ageing populations in Asia, is in the midst of an epidemiological and demographic transition. For 2022, WHO estimated that over 80% of the mortality in Sri Lanka is due to major non-communicable diseases. Among them, CVDs contribute to over 34% of deaths, impacting both life expectancy and quality of life for the past four decades. The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher

than that observed in many high-income countries. [10] Coronary artery disease (CAD) is the leading cause of death in Sri Lanka while stroke is the third highest cause of death. [11, 12]

There is evidence that childhood risk factors such as obesity, exposure to indoor and outdoor tobacco smoke, dyslipidaemia and diabetes impact cardiovascular disease in adulthood[13]; these risk factors are now being targeted for prevention of cardiovascular disease.

Birth cohort analyses have been used to determine the causal relationship between potential risk factors during the prenatal and postnatal period and the health status of the newborn up to childhood. There has been an increase in the use of birth cohort analyses.[14] They allow description of associations between early exposures and subsequent outcomes[15]; in addition, they are able to identify the risk and environmental exposure factors shared by a given generation.[16] Cohort analyses are often used to investigate disease trends [17] and for testing a wide range of hypotheses.[14]

As cardiovascular diseases are a heavy health burden in Sri Lanka, the aim of this study was to find out whether there are variations in mortality of selected cardiovascular diseases (ischaemic heart disease, hypertensive disease and cerebrovascular disease) separately for males and females over time and birth cohort among 40 – 70-year-old Sri Lankans over the period 1980-2010.

Methods

Study design and data sources

This comparative retrospective study was conducted from August 2022 to January 2024 using secondary data available in the public domain. Mortality data for Sri Lankan were extracted from the World Health Organization mortality database from 1980 through 2010 (country code 3365).[18]

Mortality data are reported annually to the WHO from the civil registration system of the country (Registrar General's department). Mortality data included the number of deaths for 5-year age groups and coded as per the International Classification of Diseases (ICD) versions 9 (1979 up to 1992) and 10 (1993 to 2021). The 10th revision of the ICD was used in Sri Lanka from 1997 onwards.[19] Separate ICD codes are given for different causes of deaths falling under cardiovascular diseases. The ICD codes used for deaths due to ischaemic heart disease, hypertensive disease and cerebrovascular diseases in the 9th and 10th revisions used in this study are given in Supplementary Table 1.

For each disease category, deaths of 5-year age groups (40-44, 45-49, 50-54, 55-59, 60-64 and 65-69) were extracted from the database for the codes and subcodes given in Supplementary Table 1 from 1980 to 2010.

The birth cohorts for different age groups corresponding to the selected years of data extraction are given in Supplementary Table 2. For example, the age group 40-44 years in 1980 belonged to the 1936-1940 birth cohort. Likewise, the age group 65-69 years in 1980 belonged to the 1911-1915 birth cohort. For each birth cohort, the number of deaths for each group of ICD codes were summed for the age group studied. For example, for the birth cohort of 1936-1940, deaths coded as B27 (9th revision) were summed for the 40-44 year age group in 1980 (birth cohort of 1936-1940).

Mortality data from 1987 to 1995 were not available on the WHO website. Mortality data for 1990 was obtained by linear interpolation of the number of deaths separately for males and females in the different age groups considered. Mortality data for 1995 were obtained from the vital statistics section of the Registrar General's Department, Sri Lanka by age group and sex.

Population data by age group and sex were obtained from the database displayed in the UN population website[21], Sri Lanka being coded as 144. Population data are displayed as estimates for inter-censal years as estimated by the Department of Census and Statistics of Sri Lanka and reported to the UN; during the census years, the actual figures are provided. Population data are reported for 5-year age groups as done for mortality data by sex.

Extracted mortality and population data were tabulated to yield six, five-year age groups from 40–44 to 65–69 years, and seven quinquennial demographic profiles from 1980 to 2010 for the 12 birth cohorts.

Data analysis

Data were entered in Excel worksheets. Mortality rates for each of the three cardiovascular diseases for each age category of both sexes were calculated based on the following formula.

Mortality rate for each age-sex category = (deaths / population) * 100,000

Using the calculated mortality rates for each age group and birth cohort, trends were determined to identify birth cohort and age effects by sex. Data are presented as tables and graphs.

To compare sex differences in specific mortality rates of 40–70-year-old Sri Lankans from 1980-2010, mortality rates of the 1936-1940 birth cohort for which all age groups were included in the analyses were plotted against the age groups; using multiple regression analysis, the slopes of the regression lines using mortality rates as the dependent variable and age as the independent variable between males and females were compared.

Ethics statement

As secondary data were used in this study, the Ethics Review Committee of the Faculty of Medicine, University of Kelaniya, Sri Lanka, exempted this study from ethics review (Ref No. P/149/11/2022).

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Results

The mortality rates due to ischaemic heart disease, hypertensive disease and cerebrovascular disease by age group, birth cohort and sex are given in Figures 1-3 and supplementary tables 3-5, respectively.

Mortality rates due to ischaemic heart disease increased with age among both males and females in each birth cohort (Figure 1 and Supplementary Table 3), the rates being higher in males than in females for each age group in each birth cohort. The mortality rates due to ischaemic heart disease for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females. In each age group, the mortality rates of each birth cohort peaked corresponding to year 2000 in both males and females after which there is a gradual decline; a spike in the mortality rates due to ischaemic heart disease seen in all birth cohorts in different age groups in year 2000 progressively declines with each subsequent birth cohort.

Similar to mortality rates due to ischaemic heart disease, mortality rates due to hypertensive disease increased with age among both males and females (Figure 2 and Supplementary Table 4); the mortality rates were higher in males than in females for each birth cohort. The highest mortality rates due to hypertensive disease for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females, the rates in the males being higher than in the females. Among both males and females, the mortality rates due to hypertensive disease of the 65-69 age group increased from the 1911-1915 to the 1941-1945 birth cohorts; again spikes are seen in the mortality rates corresponding to year 2000. In the 1936-1940 birth cohort, the mortality rate due to hypertensive disease increased from 8.4 per 100,000 population in the 40-44 year age group to 167.1 per 100,000 population in the 65-69 age group. Similar to the trends in ischaemic heart disease, a spike in the mortality rates due to hypertensive disease is seen in all birth cohorts in different age groups corresponding to year 2000.

Similar to ischaemic heart disease and hypertensive disease, mortality due to cerebrovascular disease (CeVD) increased with age among both males and females (Figure 3 and Supplementary Table 5) with the mortality rates being higher in males than in females for each birth cohort; the mortality rates due to CeVD for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females. Unlike the distinct spike in mortality rates due to ischaemic heart disease and hypertensive disease corresponding to year 2000 data, the spike for CeVD mortality rates was less marked. The mortality rates due to cerebrovascular diseases among males of the earlier cohorts for the older age groups (the 65-69 year age group of the 1926-1930 cohort and the 60-64 year age group of the 1931-1935 cohort)

peaked corresponding to year 1995; among females, this peak was less distinct for the same year. In subsequent birth cohorts, the mortality rates have been declining for each age group.

Figure 4 shows the mortality rates due to IHD, HTN and CeVD among 40–70-year-old Sri Lankans of birth cohort 1936-1940 by sex. Mortality rates for all three causes show an increasing trend in both sexes and the mortality rates of males are higher than that of females; there is a significant difference in the mortality rates for all three causes with age between males and females ($p<0.05$).

Discussion

The findings of this study show age, sex and 5-year birth cohort effects of selected cardiovascular deaths in 40-70-year-old Sri Lankans from 1980-2010. As expected, cardiovascular mortality rates due to IHD, HTN and CeVD increased with age; in each age group, mortality rates were higher among men. In the older age groups, the mortality rates due to HTN increased in the early cohorts till about 2000; in the subsequent cohorts, age group mortality continued to decrease over time. Moratlity rates to CeVD in males peaked in the older age groups (65-69 and 60-64) corresponding to 1995 with a decline in younger cohorts and over time; among females, the trend was less marked. Although the number of deaths increased with time for different age groups due to an ageing population, the mortality rates decreased with each birth cohort.

An age-period-cohort study of CVD in Japan using data from 1995-2018 showed that mortality rates of both sexes increase with age[22], similar to what we report here. The Japanese study also revealed the association between other co-morbidities with advancing age, such as diabetes mellitus, and atherosclerosis and age-related changes in the cardiovascular system such as reduced elasticity in blood vessels, increased arterial stiffness and hypertrophy of the heart etc.

could be probable causes for the higher mortality in older age.[22] Another Japanese study on mortality due to IHD from 1955 to 2000 showed non-linear birth cohort effects with an initial increase and then a decreasing trend in both sexes.[16]

Our findings suggest that mortality rates due to HTN starts to rise after about 50 years of age. Again, there are birth cohort effects with younger cohorts having lower mortality rates; the mortality rates for males are higher than that for females. [23] In Mexico, mortality due to hypertension affected more women than men. In recent cohorts, the risk of dying from hypertension is two times higher in men compared to women. Hypertensive kidney disease is the main underlying cause, with an average increase throughout the study period.[23]

Similar to the trends of HTN, CeVDs, mortality rates are relatively constant in younger birth cohorts up to about 50 years. After 1985, there is a declining trend in mortality across the birth cohorts. Similar findings were reported from China where age-standardized stroke mortality rates started declining in every age group.[24] In Japan, age-standardized stroke morality rates have declined from 98 in 1990, to 74 in 2000, to 50 in 2010, and to 33 in 2019 in males; among females, the decline was from 69 in 1990, to 46 in 2000, 27 in 2010, and to 18 in 2019. [25, 26]

In this study, the overall mortality rates of males are higher than that of females for all three cardiovascular diseases. Similar results were reported from southern Spain [27] and China.[28] The differences in mortality between males and females are partly due to biological differences including the protective effect of oestrogen in females; after menopause this effect gradually declines but the prevalences of other risk factors are lower than that of males. Other factors such as healthcare-seeking behaviour and social determinants also influence these differences. In Sri Lanka, females are subjected to routine screening at different ages during their lifetime from birth

including antenatal and postnatal care clinics and well woman clinics; female attendance at healthy lifestyle centres where screening for CVD risk factors is done is much higher than that of males.

An interesting feature in our analysis is the spikes seen in mortality rates of all three cardiovascular deaths. For IHD and HTN the spikes corresponded to data of year 2000; for CeVD the spike was less conspicuous. A possible reason for this observation is the change of the ICD coding from version 9 to 10 in 1997 despite ICD-10 being released in 1995[19]; ICD version 10 had more specific cause of death codes and had more causes of death for each disease which is likely to have increased the mortality rates for each cause of death. The subsequent decrease in the mortality rates may be due to the natural decrease in the mortality rates seen with successive birth cohorts.

Mortality rates of all three cardiovascular diseases considered show similar trends; like all non-communicable diseases, these disease entities share distinct common characteristics that are influenced by a broader range of lifestyle factors such as smoking, diet, physical activity, and obesity.

Decline in mortality rates in successive birth cohorts may be due to many factors. Firstly, it may be due to differences in exposures *in utero*, childhood and even adulthood. Implementation of screening programmes, advances in medical and surgical procedures have contributed largely to early diagnosis and secondary prevention increasing the life expectancy of those diagnosed with cardiovascular diseases.[7] In addition, large declines in smoking due to increased public awareness and regulation, including heavy taxation, are now considered a "best buy" for reduction of cardiovascular disease.[7] Ma et al. (2008) suggested that lower mortality in younger birth cohorts in Japan was probably a result of improvements in lifestyle factors, including the

national hypertension control prevention programme and improved nutrition in Japan during the previous few decades.[16]

Over several decades the Sri Lanka's health system has improved tremendously in all aspects achieving impressive health indicators comparable to those of developed countries but at a much lower cost. This achievement is attributable to an excellent preventive health service originally initiated in 1926; though initially concentrating on maternal and child health, the service has been extended to cover environmental health and later to non-communicable diseases after the inclusion of prevention and control of non-communicable diseases in the first national health policy based on primary health care and subsequently revised with a focus on universal health coverage.[29] Simultaneously, clinical services were improved and expanded with an increase in the number of hospital beds, advancements in technology and other related services. The number of doctors per 10,000 population has increased from 1401 in 1991 to 11,924 in 2021[30]. Initially, general physicians in medical wards treated cardiology patients; subsequently since the early 1970's cardiology as a specialty emerged in Sri Lanka. Specialisation in cardiology and cardiothoracic surgery followed and special units were created; in 2020, there were 644 inward beds for cardiology compared to 470 in 2008 [31, 32]. The improvement and expansion of healthcare services and the emergence of cardiology as a specialty beginning in the 1970's explains the high mortality rates in older age groups of early cohorts.

In Sri Lanka, health promotion activities carried out by the Ministry of Health at national level are likely to have contributed to improvements in cardiovascular health among the younger generations: these include, tobacco control measures (both policy and legislation); nutrition and food policies to address obesity and high lipid levels; and health promotion to raise awareness about the importance of cardiovascular health and the prevention of CVDs.[33]

Data for 1990 and 2008 were not available and data were interpolated separately for males and females. We acknowledge the fact that the validity of our results is dependent on the accuracy and reliability of mortality data and the vital statistics registration system of the country. Studies have reported that cause of death certification is not 100% accurate, as expected. [34, 35] However, given the CVD causes of death that we investigated it is unlikely to have adversely impacted on our results; the rates were calculated based on large denominators that would have little or no effect on the overall mortality rates.

Conclusions

There are age, period and birth cohort effects on mortality due to IHD, HTN and CeVD among 40-70-year-old male and female Sri Lankans between 1980 and 2010. Mortality increased with age and declined in younger cohorts over time as compared to older cohorts. Males had higher mortality rates than females for each age group in each birth cohort.

It is likely that age-sex specific mortality rates due to cardiovascular diseases will decline further, but at a much lower rate, provided that prevention and control measures for CVD risk factors are enhanced and sustained; however, the number of deaths due to cardiovascular diseases will increase due to the increasing ageing population for which adequate care facilities should be improved, expanded and provided.

Contributors

DTHDeS, EDSMDeA, DMDeM, AHDDeS and ARW contributed to the conceptualisation and developing the methodology. ARW supervised data collection. All authors were involved in data curation, data analysis, writing the original draft, and reviewing and editing the final draft. ARW accepts full responsibility for the work and conduct of the study.

Funding

The authors received no funding for this study.

Competing interests

All authors have no competing interests to declare.

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

Acknowledgements

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Legend for figures

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel $1a_1$-Mortality rates by age for different birth cohorts in males; Panel $1a_2$-Mortality rates by birth cohorts for different age groups in males; Panel $1b_1$-Mortality rates by age for different birth cohorts in females; Panel $1b_2$-Mortality rates by birth cohorts for different age groups in females)

Figure 2. Mortality rates due to Hypertensive disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel $2a_1$-Mortality rates by age for different birth cohorts in males; Panel $2a_2$-Mortality rates by birth cohorts for different age groups in males; Panel $2b_1$-Mortality rates by age for different birth cohorts in females; Panel $2b_2$-Mortality rates by birth cohorts for different age groups in females)

Figure 3. Mortality rates due to Cerebrovascular disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel $3a_1$-Mortality rates by age for different birth cohorts in males; Panel $3a_2$-Mortality rates by birth cohorts for different age groups in males; Panel $3b_1$-Mortality rates by age for different birth cohorts in females; Panel $3b_2$-Mortality by birth cohorts for different age groups in females)

Figure 4. Sex differences in mortality rates by age group between males and females in the 1936-1940 birth cohort.

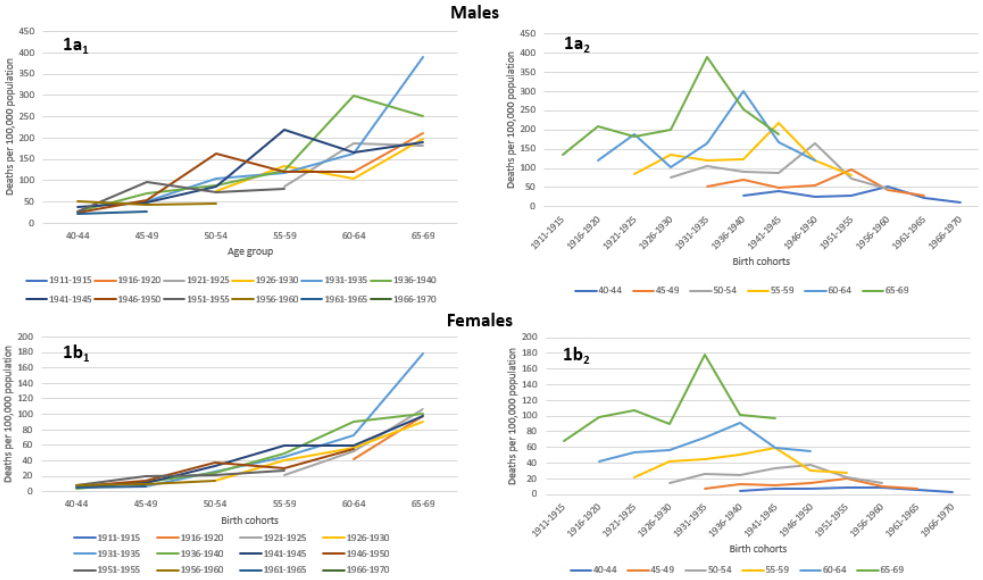

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 1a1-Mortality rates by age for different birth cohorts in males; Panel 1a2-Mortality rates by birth cohorts for different age groups in males; Panel 1b1-Mortality rates by age for different birth cohorts in females; Panel 1b2-Mortality rates by birth cohorts for different age groups in females)

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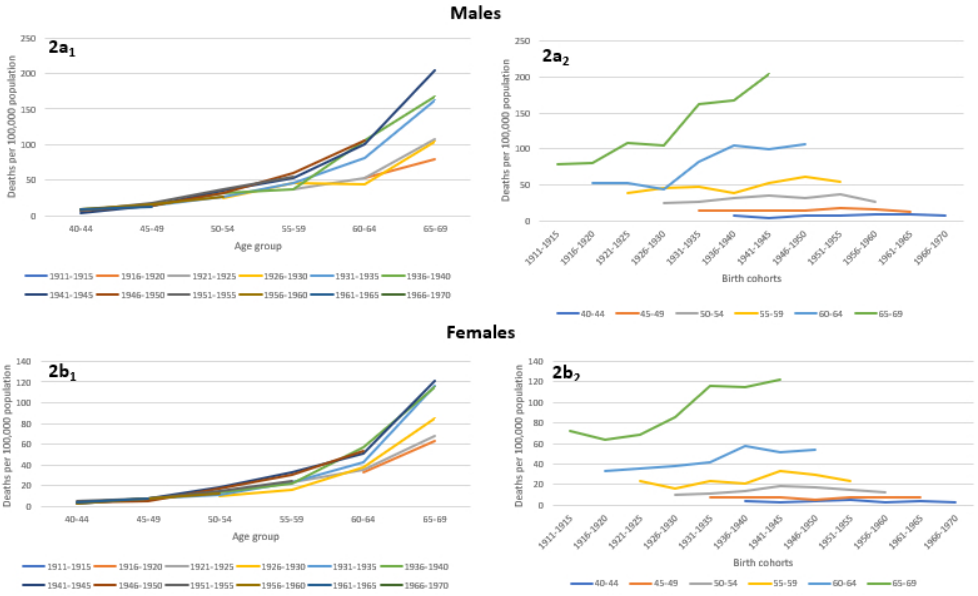

Figure 2. Mortality rates due to Hypertensive disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 2a1-Mortality rates by age for different birth cohorts in males; Panel 2a2-Mortality rates by birth cohorts for different age groups in males; Panel 2b1-Mortality rates by age for different birth cohorts in females; Panel 2b2-Mortality rates by birth cohorts for different age groups in females)

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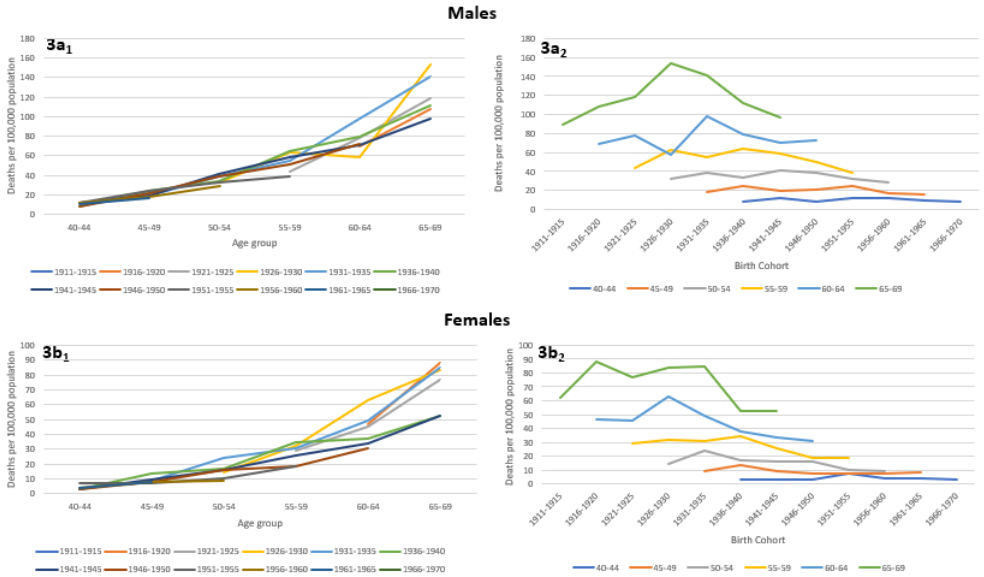

Figure 3. Mortality rates due to Cerebrovascular disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (Panel 3a1-Mortality rates by age for different birth cohorts in males; Panel 3a2-Mortality rates by birth cohorts for different age groups in males; Panel 3b1-Mortality rates by age for different birth cohorts in females; Panel 3b2-Mortality by birth cohorts for different age groups in females)

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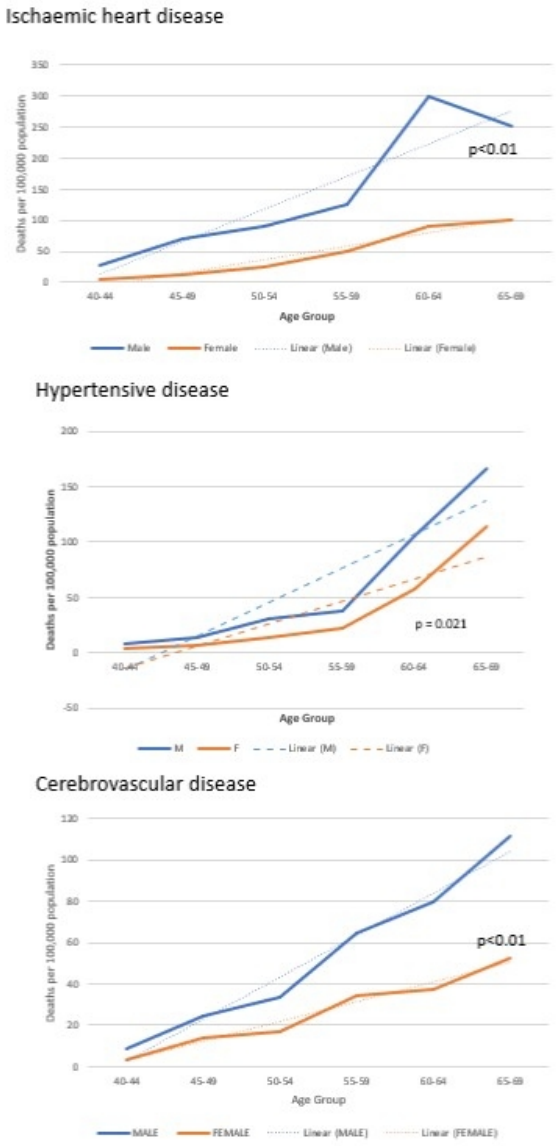

Figure 4. Sex differences in mortality rates by age group between males and females in the 1936-1940 birth cohort.

111x203mm (96 x 96 DPI)

Supplementary Table 1. Cause of death codes of selected conditions of the International Classification of Diseases versions 9 and 10

Cause of death	ICD-9		ICD-10	
	Code	**Subcode**	**Code**	**Subcode**
Ischaemic Heart Disease	B27		1067	I20-I25
Acute myocardial infarction		B270		I21
Remainder		B279		I20, I22, I23, I24, I25
Hypertensive Disease	B26		1066	I10-I13
Hypertensive heart disease		B260		I11
Remainder		B269		I10, I12, I13
Cerebrovascular disease	B29		1069	I60-I69
Subarachnoid hemorrhage		B290		I60
Intracerebral and other intracranial hemorrhage		B291		I61
Cerebral infarction		B292		I63
Others		B293, B294, B299		I62, I64-I69

Source: WHO. Mortality database[20]

Supplementary Table 2. Birth cohorts corresponding to different age groups 1980-2010

Age Group	Year						
	1980	1985	1990	1995	2000	2005	2010
40-44	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
45-49	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
50-54	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960
55-59	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955
60-64	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950
65-69	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945

Supplementary Table 3. Deaths due to Ischaemic Heart Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						28.42	40.02	25.58	28.23	52.84	23.41	13.03
45-49					51.52	70.20	50.26	55.83	96.02	42.97	28.85	
50-54				75.26	105.89	90.60	87.68	164.23	73.50	47.65		
55-59			85.97	135.67	119.64	124.77	219.60	120.39	81.31			
60-64		120.35	187.19	104.35	163.57	300.37	167.23	122.23				
65-69	136.73	210.55	182.50	199.57	389.99	252.12	189.32					
Females												
40-44						3.77	6.77	7.53	9.22	8.68	5.86	3.71
45-49					7.76	12.95	11.28	14.97	20.53	10.41	6.91	
50-54				14.87	25.59	24.69	33.07	37.18	22.29	15.02		
55-59			21.37	41.48	45.29	50.24	60.21	30.40	27.42			
60-64		42.14	53.13	57.32	72.83	91.09	59.50	55.25				
65-69	68.17	98.12	106.77	90.38	177.83	100.98	97.80					

Supplementary Table 4. Deaths due to Hypertensive Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	4.23	7.40	7.44	8.81	8.61	7.04
45-49					14.40	14.28	15.03	14.34	17.48	15.63	12.39	
50-54				24.28	27.24	31.35	35.23	31.63	36.95	27.15		
55-59			38.21	45.84	46.91	38.24	53.28	60.80	54.55			
60-64		52.62	52.80	44.06	82.18	105.20	99.89	106.07				
65-69	78.76	80.00	108.50	104.23	162.42	167.07	204.82					
Females												
40-44						4.06	2.51	3.77	4.71	2.95	3.81	2.28
45-49					7.08	7.23	7.95	5.77	8.13	7.65	7.06	
50-54				9.53	11.57	13.58	18.37	17.16	14.55	12.60		
55-59			23.64	16.35	23.19	21.62	33.36	29.96	23.93			
60-64		33.36	35.26	38.08	42.27	57.18	50.96	53.51				
65-69	71.96	63.49	68.23	85.46	116.66	114.62	121.64					

Supplementary Table 5. Deaths due to Cerebrovascular Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	12.18	8.67	11.63	12.29	10.12	8.84
45-49					18.88	24.39	19.69	21.18	24.51	17.83	16.46	
50-54				32.95	38.48	33.54	41.24	39.13	32.11	28.73		
55-59			43.39	62.99	54.55	64.40	58.58	50.67	39.23			
60-64		69.19	77.67	57.97	98.14	79.55	70.24	72.48				
65-69	89.47	108.33	118.50	153.30	141.01	111.52	97.43					
Females												
40-44						3.48	3.51	3.35	7.34	3.93	3.81	3.42
45-49					9.10	13.55	9.49	7.70	7.36	7.65	7.94	
50-54				14.49	23.84	16.98	16.01	15.84	10.39	8.88		
55-59			29.10	31.91	30.80	34.66	26.04	18.81	18.59			
60-64		46.82	45.41	62.76	49.44	37.56	33.88	31.01				
65-69	62.11	87.86	77.08	83.67	85.07	52.33	52.26					

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Cardiovascular Mortality of 40–70-year-olds in Sri Lanka from 1980 - 2010; a birth cohort analysis by age and sex

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Abstract

Objectives

To compare cardiovascular mortality (ischaemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD)) of 40–70-year-old Sri Lankans from 1980-2010 by age, birth cohort and sex.

Design

A comparative retrospective study

Setting

Sri Lanka

Participants

40-70-year-old Sri Lankans from 1980-2010.

Primary and secondary outcome measures

Cardiovascular deaths due to IHD, HTN and CeVD.

Results

Mortality due to IHD increased with age but decreased with birth cohorts with time (range 3.7-390 per 100,000 population); there was a spike in the IHD mortality rates in both age-groups and birth cohorts in 2000. Deaths due to HTN markedly increased after 55 years; however, mortality decreased in the younger cohorts (range 2.8-204.81 per 100,000 population). CeVD mortality linearly increased with age (range 3.3-153.3 per 100,000 population); birth cohorts of 1926-1930 and

1931-1935 had a spike in mortality among 60-64 and 65-69 age groups, respectively. Changes were seen among both males and females; mortality rates were higher in males than in females.

Conclusions

All cardiovascular mortality rates increase with age and are higher in males than in females. Age specific cardiovascular mortality rates are lower in the younger birth cohorts as compared to the older birth cohorts. The increase in cardiovascular deaths in Sri Lanka is due to the ageing population.

Keywords: Cardiovascular mortality, 1980-2010, 40-70-year-olds, Sri Lanka

Strengths and limitations of this study

- The study aimed to compare cardiovascular mortality (ischaemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD)) of 40–70-year-old Sri Lankans from 1980-2010 by age, birth cohort and sex, the first such analysis done in the country.
- Birth cohort analysis of mortality due to cardiovascular diseases by age and sex show trends in mortality and allows comparisons over time.
- The results depend on the accuracy and reliability of mortality data over time.
- Inability to determine the relationship between mortality and economic indicators due to lack of data is a limitation of the study.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally. They comprise a group of diseases of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular disease (CeVD), peripheral artery disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis and pulmonary embolism.[1]

In 2019, it was estimated that there were 17.9 million deaths due to CVDs accounting for 32% of all global deaths; of these deaths, 85% were due to heart attack and stroke. More than 75% of all CVD deaths occur in low- and middle-income countries; CVD deaths comprised 38% of premature deaths (under the age of 70) due to non-communicable diseases. [1]

Hypertension, defined as having a blood pressure above 140/90, is a leading risk factor for cardiovascular disease with a heavy public health burden worldwide. [2] Poorly controlled or uncontrolled blood pressure increases the risk of hypertensive disease (HTN) giving rise to microscopic and macroscopic cardiac remodeling and functional alterations.[3] It is estimated that 1.28 billion adults aged 30–79 years worldwide have hypertension with two-thirds living in low- and middle-income countries.[4] 46% of hypertensives are unaware they have the condition and less than 42% are diagnosed and treated; only 21% of adults with hypertension have it controlled.[4] It is a major cause of premature death worldwide.[4]

The number of CVD deaths has been increasing over time; in 2000, around 14 million people died from cardiovascular diseases globally, while in 2019, close to 18 million died.[5] It is estimated that CVDs would account for >23 million deaths by 2030.[6] The decline in incidence and mortality rates for developed countries was significantly higher than those for developing countries from 1990–2017 ($p < 0.05$); developing nations had a less-steeper decline.[7]

Risk factors for cardiovascular diseases include age, sex and other modifiable lifestyle risk factors.[7] The rising death toll is largely due to a growing and ageing global population. Death rates have been declining due to implementation of preventive programmes; large declines in smoking, improvements in screening, diagnosis, and monitoring; and advances in medical treatments, public health initiatives, emergency care, and surgical procedures have all helped to reduce the impact of cardiovascular diseases on people's lives.[7] The large disparities that still exist can be further reduced.

South Asia has a disproportionately high burden of cardiovascular disease, with higher rates of CVD incidence, mortality, and risk factor prevalences than many other regions.[8] Cardiovascular diseases account for 3.9 million deaths in the WHO South-East Asia Region every year, comprising a quarter of all deaths from non-communicable diseases (NCDs), with most of them being preventable.[9] Even though South Asians comprise only 25% of the world's population, they account for more than 50% of the world's cardiovascular deaths.[8]

Sri Lanka, a country having one of the fastest ageing populations in Asia, is in the midst of an epidemiological and demographic transition. In 2022, WHO estimated that over 80% of the mortality in Sri Lanka is due to major non-communicable diseases with CVDs contribute to over 34% of deaths, impacting both life expectancy and quality of life. The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher than that observed in many high-income countries. [10] Coronary artery disease (CAD) is the leading cause of death in Sri Lanka while stroke is the third highest cause of death. [11, 12]

There is evidence that childhood risk factors such as obesity, exposure to indoor and outdoor tobacco smoke, dyslipidaemia and diabetes impact cardiovascular disease in adulthood[13]; these risk factors are now being targeted for prevention of cardiovascular disease.

Birth cohort analyses have been used to determine the causal relationship between potential risk factors during the prenatal and postnatal period and the health status of the newborn up to childhood. Birth cohort analyses allow description of associations between early exposures and subsequent outcomes[14, 15]; in addition, they are able to identify the risk and environmental exposure factors shared by a given generation, are used to investigate disease trends and test a wide range of hypotheses. [14-17] Birth cohort analyses of CVDs have not been conducted in Sri Lanka. The aim of this study was to find out whether there are variations in age and sex specific mortality rates of selected cardiovascular diseases (ischaemic heart disease, hypertensive disease and cerebrovascular disease) among 40-70-year-old Sri Lankans from 1980-2010 by birth cohort.

Methods

Study design and data sources

This comparative retrospective study was conducted from August 2022 to January 2024 using secondary data available in the public domain. Mortality data of Sri Lanka were extracted from the World Health Organization mortality database from 1980 through 2010 (country code 3365).[18] Mortality data are reported annually to the WHO from the civil registration system of the country (Registrar General's department). Mortality data included the number of deaths for 5-year age groups and coded as per the International Classification of Diseases (ICD) versions 9 (1979 up to

1992) and 10 (1993 to 2021). The 10th revision of the ICD was used in Sri Lanka from 1997 onwards.[19] Separate ICD codes are given for different causes of deaths falling under cardiovascular diseases. The ICD codes used for deaths due to ischaemic heart disease, hypertensive disease and cerebrovascular diseases in the 9th and 10th revisions used in this study are given in Supplementary Table 1.

For each disease category, deaths of 5-year age groups (40-44, 45-49, 50-54, 55-59, 60-64 and 65-69) were extracted from the database for the codes and subcodes given in Supplementary Table 1 from 1980 to 2010.

The birth cohorts for different age groups corresponding to the selected years of data extraction are given in Supplementary Table 2. For example, the age group 40-44 years in 1980 belonged to the 1936-1940 birth cohort. Likewise, the age group 65-69 years in 1980 belonged to the 1911-1915 birth cohort. For each birth cohort, the number of deaths for each group of ICD codes were summed for the age group studied. For example, for the birth cohort of 1936-1940, deaths coded as B27 (9th revision) were summed for the 40-44 year age group in 1980 (birth cohort of 1936-1940).

Mortality data from 1987 to 1995 were not available on the WHO website. Mortality data for 1990 was obtained by linear interpolation of the number of deaths separately for males and females in the different age groups considered. Mortality data for 1995 were obtained from the vital statistics section of the Registrar General's Department, Sri Lanka by age group and sex.

Population data by age group and sex were obtained from the database displayed in the UN population website[21], Sri Lanka being coded as 144. Population data are displayed as estimates for inter-censal years as estimated by the Department of Census and Statistics of Sri Lanka and

reported to the UN; during the census years, the actual figures are provided. Population data are reported for 5-year age groups as done for mortality data by sex.

Extracted mortality and population data were tabulated to yield six, five-year age groups from 40–44 to 65–69 years, and seven quinquennial demographic profiles from 1980 to 2010 for the 12 birth cohorts.

Data analysis

Data were entered in Excel worksheets. Mortality rates for each of the three cardiovascular diseases for each age category of both sexes were calculated based on the following formula.

Mortality rate for each age-sex category = (deaths / population) * 100,000

Using the calculated mortality rates for each age group and birth cohort, trends were determined to identify birth cohort and age effects by sex. Data are presented as tables and graphs. Mortality rates of IHD, HTN and CeVD were plotted by age group, birth cohort and year by age and sex.

To compare sex differences in specific mortality rates of 40–70-year-old Sri Lankans from 1980-2010, mortality rates of the 1936-1940 birth cohort for which all age groups were included in the analyses were plotted against the age groups; using multiple regression analysis, the slopes of the regression lines using mortality rates as the dependent variable and age as the independent variable between males and females were compared.

Ethics statement

The Ethics Review Committee of the Faculty of Medicine, University of Kelaniya, Sri Lanka, exempted this study from ethics review (Ref No. P/149/11/2022).

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Results

The mortality rates due to ischaemic heart disease, hypertensive disease and cerebrovascular disease by age group, birth cohort and sex are given in Figures 1-6 and supplementary tables 3-5, respectively.

Insert figure 1 here

Mortality rates due to ischaemic heart disease increased with age among both males and females in each birth cohort (Figures 1 and 2, and Supplementary Table 3), the rates being higher in males than in females for each age group in each birth cohort each year. The mortality rates due to ischaemic heart disease for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females. In each age group, the mortality rates of each birth cohort peaked corresponding to year 2000 in both males and females after which there is a gradual decline; a spike in the mortality rates due to ischaemic heart disease seen in all birth cohorts in different age groups in year 2000 and progressively declines with each subsequent birth cohort.

Insert figure 2 here

Similar to mortality rates due to ischaemic heart disease, mortality rates due to hypertensive disease increased with age among both males and females (Figures 3and 4, and Supplementary Table 4); the mortality rates were higher in males than in females for each birth cohort and age group. The highest mortality rates due to hypertensive disease for each age group was higher among the early birth cohorts as compared to the later birth cohorts among both males and females, the rates being higher in males. Among both males and females, the mortality rates due to hypertensive disease of the 65-69 age group increased from the 1911-1915 to the 1941-1945 birth cohorts; spikes are seen in the mortality rates corresponding to year 2000. In the 1936-1940 birth cohort, the mortality rate due to hypertensive disease increased from 8.4 per 100,000 population in the 40-44-year age group to 167.1 per 100,000 population in the 65-69-year age group. Similar to the trends in ischaemic heart disease, a spike in the mortality rates due to hypertensive disease is seen in all birth cohorts in different age groups corresponding to year 2000.

Insert figures 3 and 4 here

Similar to ischaemic heart disease and hypertensive disease, mortality due to cerebrovascular disease (CeVD) increased with age among both males and females (Figures 5 and 6, and Supplementary Table 5) with the mortality rates being higher in males than in females for each birth cohort; the mortality rates due to CeVD for each age group was higher among the early birth cohorts as compared to the later birth cohorts among both males and females. Unlike the distinct spike in mortality rates due to ischaemic heart disease and hypertensive disease corresponding to year 2000 data, the spike for CeVD mortality rates was less marked. The mortality rates due to cerebrovascular diseases among males of the earlier cohorts for the older

age groups (the 65-69 year age group of the 1926-1930 cohort and the 60-64 year age group of the 1931-1935 cohort) peaked corresponding to year 1995 (Figure 6); among females, this peak was less distinct for the same year. In subsequent birth cohorts, the mortality rates have been declining for each age group.

Insert figures 5 and 6 here

Mortality rates due to IHD, HTN and CeVD among 40–70-year-old Sri Lankans of birth cohort 1936-1940 by sex are given in Supplemental figures 1-3, respectively. Mortality rates due to all three causes show an increasing trend in both sexes and the mortality rates of males being higher than that of females; there is a significant difference in the mortality rates for all three causes with age between males and females ($p<0.05$).

Discussion

The findings of this study show age, sex and 5-year birth cohort effects of selected cardiovascular deaths in 40-70-year-old Sri Lankans from 1980-2010. As expected, cardiovascular mortality rates due to IHD, HTN and CeVD increased with age; in each age group, mortality rates were higher among men. In the older age groups, the mortality rates due to HTN increased in the early cohorts till about 2000; in the subsequent cohorts, age group mortality continued to decrease over time. CeVD mortality rates in males peaked in the older age groups (65-69 and 60-64) corresponding to year 1995 with a decline in younger cohorts and over time; among females, the trend was less marked. Although the number of deaths increased with time for different age groups due to an ageing population, the mortality rates decreased with each birth cohort.

An age-period-cohort study of CVD in Japan using data from 1995-2018 showed that mortality rates of both sexes increased with age[22], similar to what is reported here. The Japanese study also revealed the association between other co-morbidities with advancing age, such as diabetes mellitus, and atherosclerosis and age-related changes in the cardiovascular system such as reduced elasticity in blood vessels, increased arterial stiffness and hypertrophy of the heart etc. could be probable causes for the higher mortality in older age.[22] Another Japanese study on mortality due to IHD from 1955 to 2000 showed non-linear birth cohort effects with an initial increase and then a decreasing trend in both sexes.[16]

The findings of this study suggest that mortality rates due to HTN starts to rise after about 50 years of age. Again, there are birth cohort effects with younger cohorts having lower mortality rates; the mortality rates for males are higher than that for females. [23] In Mexico, mortality due to hypertension affected more women than men. In recent cohorts, the risk of dying from hypertension is two times higher in men compared to women. Hypertensive kidney disease is the main underlying cause, with an average increase throughout the study period.[23]

Similar to the trends of HTN, CeVDs, mortality rates are relatively constant in younger birth cohorts up to about 50 years. After 1985, there is a declining trend in mortality across the birth cohorts. Similar findings were reported from China where age-standardized stroke mortality rates started declining in every age group.[24] In Japan, age-standardized stroke morality rates per 100,000 population have declined from 98 in 1990, to 74 in 2000, to 50 in 2010, and to 33 in 2019 in males; among females, the decline was from 69 in 1990, to 46 in 2000, 27 in 2010, and to 18 in 2019. [25, 26]

In this study, the overall mortality rates of males are higher than that of females for all three cardiovascular diseases. Similar results were reported from southern Spain [27] and China.[28] The differences in mortality between males and females are partly due to biological differences including the protective effect of oestrogen in females; after menopause this effect gradually declines but the prevalences of other risk factors are lower than that of males. Other factors such as healthcare-seeking behaviour and social determinants also influence these differences. In Sri Lanka, females are subjected to routine screening at different ages during their lifetime from birth including antenatal and postnatal care clinics and well woman clinics; female attendance at healthy lifestyle centres where screening for CVD risk factors is done is much higher than that of males.

An interesting feature in this analysis is the spikes seen in mortality rates of all three cardiovascular deaths. For IHD and HTN the spikes corresponded to data of year 2000; for CeVD the spike was less conspicuous. A possible reason for this observation is the change of the ICD coding from version 9 to 10 in 1997 despite ICD-10 being released in 1995[19]; ICD version 10 had more specific cause of death codes and had more causes of death for each disease which is likely to have increased the mortality rates for each cause of death. The subsequent decrease in the mortality rates may be due to the natural decrease in the mortality rates seen with successive birth cohorts.

Mortality rates of all three cardiovascular diseases considered show similar trends; like all non-communicable diseases, these disease entities share distinct common characteristics that are influenced by a broader range of lifestyle factors such as smoking, diet, physical activity, and obesity.

Decline in mortality rates in successive birth cohorts may be due to many factors. Firstly, it may be due to differences in exposures *in utero*, childhood and even adulthood. Implementation of

screening programmes, advances in medical and surgical procedures have contributed largely to early diagnosis and secondary prevention increasing the life expectancy of those diagnosed with cardiovascular diseases.[7] In addition, large declines in smoking due to increased public awareness and regulation, including heavy taxation, are now considered a "best buy" for reduction of cardiovascular disease.[7] Ma et al. (2008) suggested that lower mortality in younger birth cohorts in Japan was probably a result of improvements in lifestyle factors, including the national hypertension control prevention programme and improved nutrition in Japan during the previous few decades.[16] It is also likely to be due to improved economic status over time. The per capita GNI in Sri Lanka was current dollars 2510 in 1990; in 2010 it was 8150.

Over several decades the Sri Lanka's health system has improved tremendously in all aspects achieving impressive health indicators comparable to those of developed countries but at a much lower cost. This achievement is attributable to an excellent preventive health service originally initiated in 1926; though initially concentrating on maternal and child health, the service has been extended to cover environmental health and later to non-communicable diseases after the inclusion of prevention and control of non-communicable diseases in the first national health policy based on primary health care, and subsequently revised with a focus on universal health coverage.[29] Simultaneously, clinical services were improved and expanded with an increase in the number of hospital beds, advancements in technology and other related services. The number of doctors per 10,000 population has increased from 1401 in 1991 to 11,924 in 2021[30]. Initially, general physicians in medical wards treated cardiology patients; subsequently since the early 1970's cardiology as a specialty emerged in Sri Lanka. Specialisation in cardiology and cardiothoracic surgery followed and special units were created; in the public sector in 2020, there were 644 inward beds for cardiology compared to 470 in 2008 [31, 32]. The improvement and expansion of healthcare

services and the emergence of cardiology as a specialty beginning in the 1970's probably explains the high mortality rates in older age groups of early cohorts.

In Sri Lanka, preventative activities carried out by the Ministry of Health at national level are likely to have contributed to improvements in cardiovascular health among the younger generations: these include, tobacco control measures (both policy and legislation); nutrition and food policies to address obesity and high lipid levels; and health promotion to raise awareness about the importance of cardiovascular health and the prevention of CVDs.[33]

Data for 1990 and 2008 were not available and data were interpolated separately for males and females. The fact that the validity of our results is dependent on the accuracy and reliability of mortality data and the vital statistics registration system of the country is acknowledged. Studies have reported that cause of death certification is not 100% accurate, as expected. [34, 35] However, given the CVD causes of death that were investigated it is unlikely to have adversely impacted on our results; the rates were calculated based on large denominators that would have little or no effect on the overall mortality rates.

Relating the differences in mortality rates to economic indicators was not attempted. The GNI was available from 1990 onwards and requires a more detailed analysis that should be conducted in the future.

Conclusions

There are age, period and birth cohort effects on mortality due to IHD, HTN and CeVD among 40-70-year-old male and female Sri Lankans between 1980 and 2010. Mortality increased with age and declined in younger cohorts over time as compared to older cohorts. Males had higher mortality rates than females for each age group in each birth cohort.

It is likely that age-sex specific mortality rates due to cardiovascular diseases will decline further, but at a much lower rate, provided that prevention and control measures for CVD risk factors are enhanced and sustained; however, the number of deaths due to cardiovascular diseases will increase due to the increasing ageing population for which adequate care facilities should be improved, expanded and provided.

Contributors

DTHDeS, EDSMDeA, DMDeM, AHDDeS and ARW contributed to the conceptualisation and developing the methodology. ARW supervised data collection. All authors were involved in data curation, data analysis, writing the original draft, and reviewing and editing the final draft. ARW is the guarantor and accepts full responsibility for the work and conduct of the study.

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Competing interests

All authors have no competing interests to declare.

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

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Figure legends

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (panel a_1-mortality rates by age for different birth cohorts among males; panel a_2-mortality rates by birth cohorts for different age groups among males; panel b_1-mortality rates by age for different birth cohorts among females; panel b_2-mortality rates by birth cohorts for different age groups among females)

Figure 2. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 3. Mortality rates due to Hypertensive disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (panel a_1-mortality rates by age for different birth cohorts in males; panel a_2-mortality rates by birth cohorts for different age groups in males; panel b_1-mortality rates by age for different birth cohorts in females; panel b_2-mortality rates by birth cohorts for different age groups in females)

Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 5. Mortality rates due to Cerebrovascular disease among 40-70-year-old Sri Lankans by age groups, birth cohort and sex. (panel a_1-mortality rates by age for different birth cohorts in males; panel a_2-mortality rates by birth cohorts for different age groups in males; panel b_1-mortality rates by age for different birth cohorts in females; panel b_2-mortality by birth cohorts for different age groups in females)

Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Supplemental figure 1. Sex differences in mortality rates due to IHD by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 2. Sex differences in mortality rates due to HTN by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 3. Sex differences in mortality rates due to CeVD by age group in males and females of the 1936-1940 birth cohort.

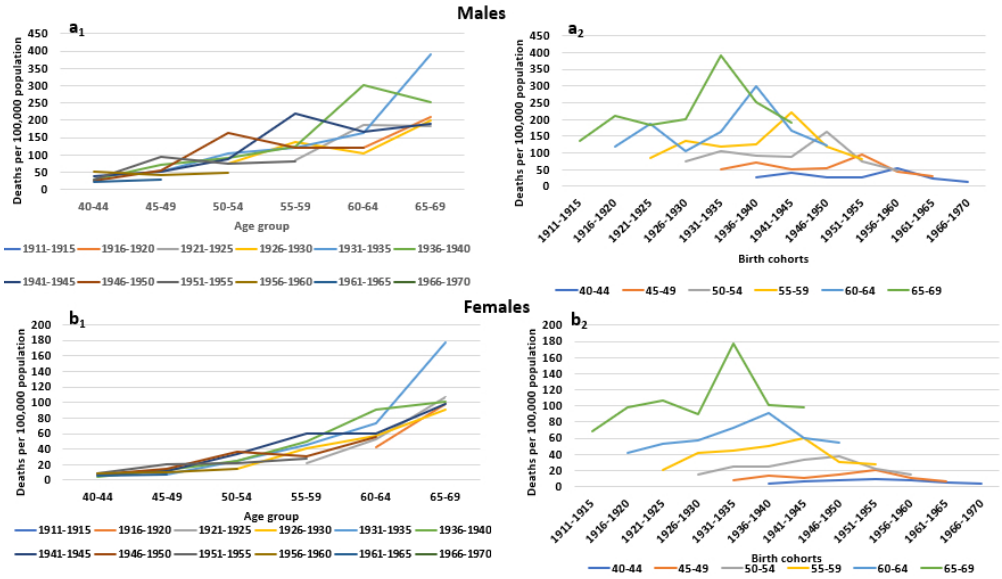

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts among males; panel a2-mortality rates by birth cohorts for different age groups among males; panel b1-mortality rates by age for different birth cohorts among females; panel b2-mortality rates by birth cohorts for different age groups among females)

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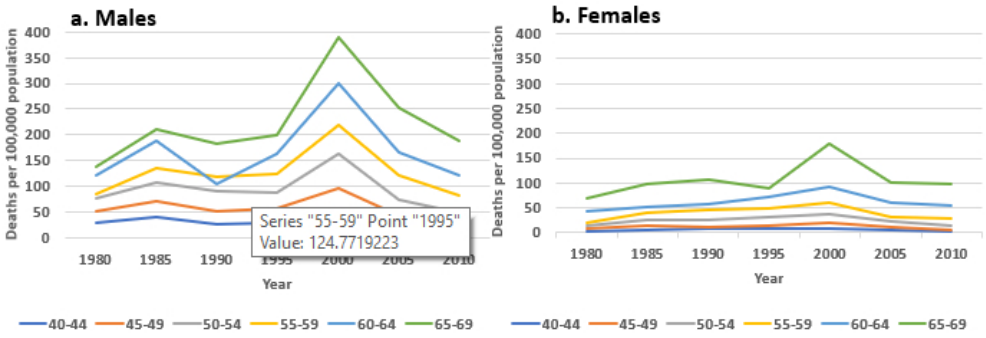

Figure 2. Mortality rates due to Ischaemic Heart disease among 40-70-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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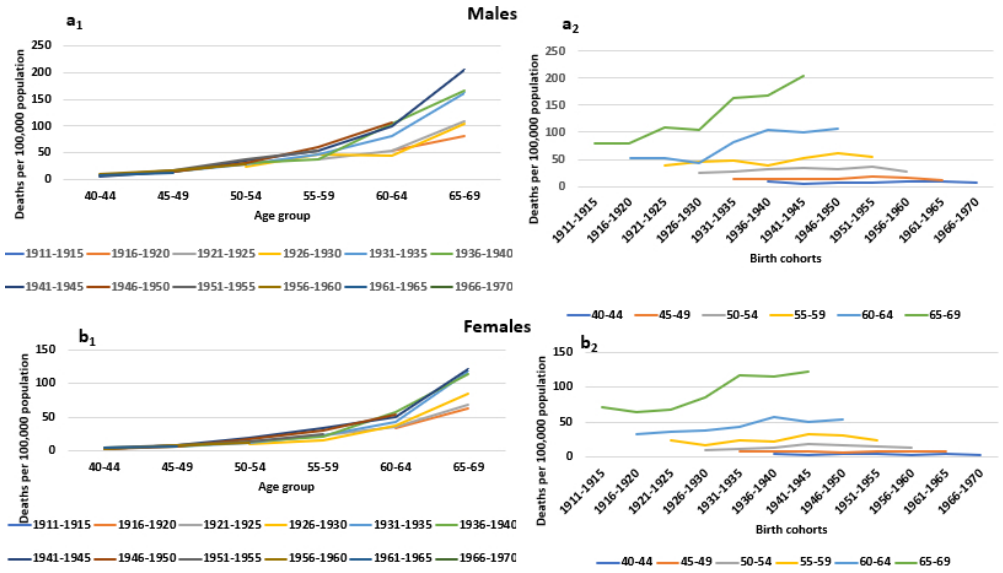

Figure 3. Mortality rates due to Hypertensive disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality rates by birth cohorts for different age groups in females)

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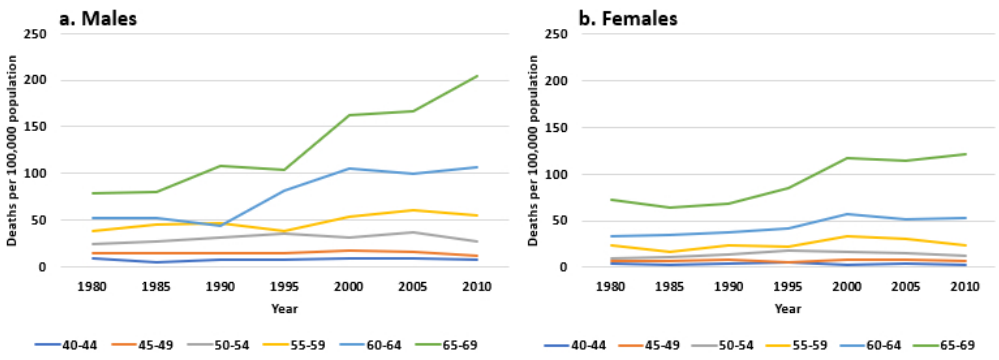

Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

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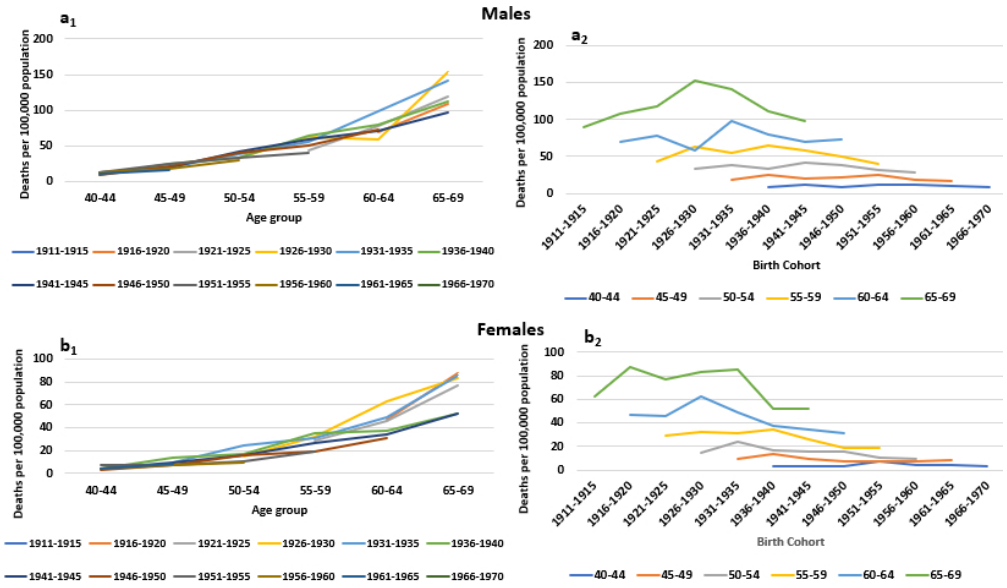

Figure 5. Mortality rates due to Cerebrovascular disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality by birth cohorts for different age groups in females)

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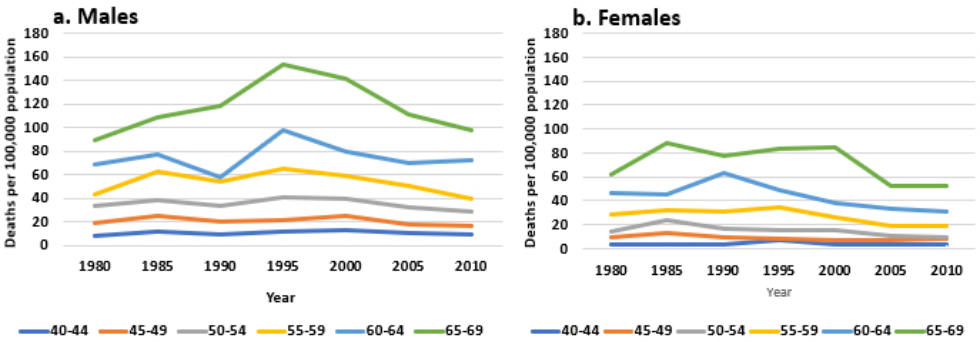


Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

468x171mm (38 x 38 DPI)

Supplementary Table 1. Cause of death codes of selected conditions of the International Classification of Diseases versions 9 and 10

Cause of death	ICD-9		ICD-10	
	Code	**Subcode**	**Code**	**Subcode**
Ischaemic Heart Disease	B27		1067	I20-I25
Acute myocardial infarction		B270		I21
Remainder		B279		I20, I22, I23, I24, I25
Hypertensive Disease	B26		1066	I10-I13
Hypertensive heart disease		B260		I11
Remainder		B269		I10, I12, I13
Cerebrovascular disease	B29		1069	I60-I69
Subarachnoid hemorrhage		B290		I60
Intracerebral and other intracranial hemorrhage		B291		I61
Cerebral infarction		B292		I63
Others		B293, B294, B299		I62, I64-I69

Source: WHO. Mortality database[20]

Supplementary Table 2. Birth cohorts corresponding to different age groups 1980-2010

Age Group	Year						
	1980	1985	1990	1995	2000	2005	2010
40-44	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
45-49	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
50-54	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960
55-59	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955
60-64	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950
65-69	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945

Supplementary Table 3. Deaths due to Ischaemic Heart Disease per 100,000 population in Sri Lanka by birth cohort and age group

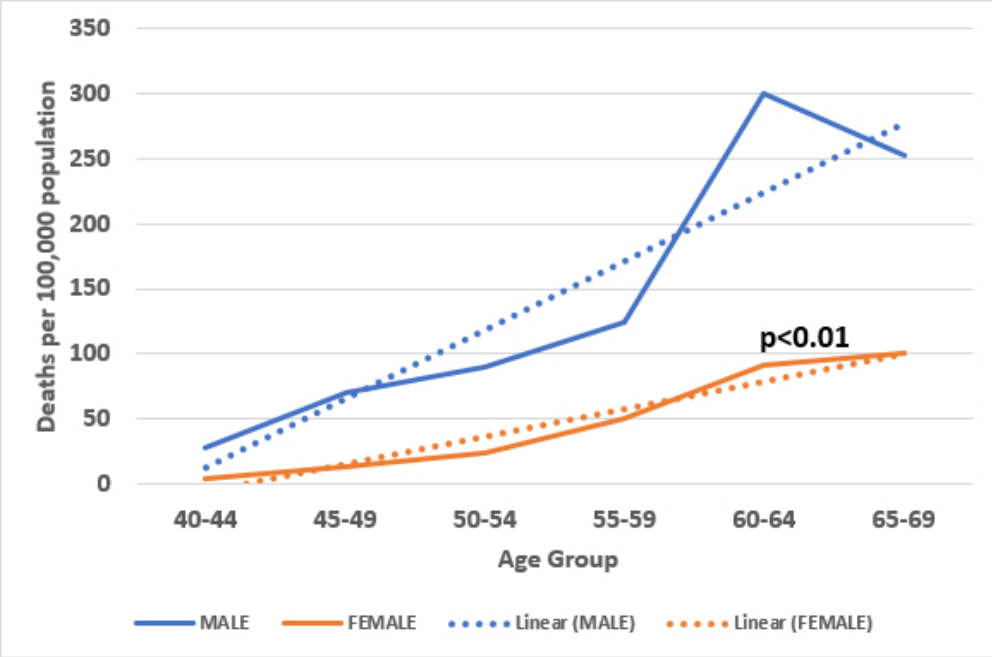
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						28.42	40.02	25.58	28.23	52.84	23.41	13.03
45-49					51.52	70.20	50.26	55.83	96.02	42.97	28.85	
50-54				75.26	105.89	90.60	87.68	164.23	73.50	47.65		
55-59			85.97	135.67	119.64	124.77	219.60	120.39	81.31			
60-64		120.35	187.19	104.35	163.57	300.37	167.23	122.23				
65-69	136.73	210.55	182.50	199.57	389.99	252.12	189.32					
Females												
40-44						3.77	6.77	7.53	9.22	8.68	5.86	3.71
45-49					7.76	12.95	11.28	14.97	20.53	10.41	6.91	
50-54				14.87	25.59	24.69	33.07	37.18	22.29	15.02		
55-59			21.37	41.48	45.29	50.24	60.21	30.40	27.42			
60-64		42.14	53.13	57.32	72.83	91.09	59.50	55.25				
65-69	68.17	98.12	106.77	90.38	177.83	100.98	97.80					

Supplementary Table 4. Deaths due to Hypertensive Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	4.23	7.40	7.44	8.81	8.61	7.04
45-49					14.40	14.28	15.03	14.34	17.48	15.63	12.39	
50-54				24.28	27.24	31.35	35.23	31.63	36.95	27.15		
55-59			38.21	45.84	46.91	38.24	53.28	60.80	54.55			
60-64		52.62	52.80	44.06	82.18	105.20	99.89	106.07				
65-69	78.76	80.00	108.50	104.23	162.42	167.07	204.82					
Females												
40-44						4.06	2.51	3.77	4.71	2.95	3.81	2.28
45-49					7.08	7.23	7.95	5.77	8.13	7.65	7.06	
50-54				9.53	11.57	13.58	18.37	17.16	14.55	12.60		
55-59			23.64	16.35	23.19	21.62	33.36	29.96	23.93			
60-64		33.36	35.26	38.08	42.27	57.18	50.96	53.51				
65-69	71.96	63.49	68.23	85.46	116.66	114.62	121.64					

Supplementary Table 5. Deaths due to Cerebrovascular Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	12.18	8.67	11.63	12.29	10.12	8.84
45-49					18.88	24.39	19.69	21.18	24.51	17.83	16.46	
50-54				32.95	38.48	33.54	41.24	39.13	32.11	28.73		
55-59			43.39	62.99	54.55	64.40	58.58	50.67	39.23			
60-64		69.19	77.67	57.97	98.14	79.55	70.24	72.48				
65-69	89.47	108.33	118.50	153.30	141.01	111.52	97.43					
Females												
40-44						3.48	3.51	3.35	7.34	3.93	3.81	3.42
45-49					9.10	13.55	9.49	7.70	7.36	7.65	7.94	
50-54				14.49	23.84	16.98	16.01	15.84	10.39	8.88		
55-59			29.10	31.91	30.80	34.66	26.04	18.81	18.59			
60-64		46.82	45.41	62.76	49.44	37.56	33.88	31.01				
65-69	62.11	87.86	77.08	83.67	85.07	52.33	52.26					



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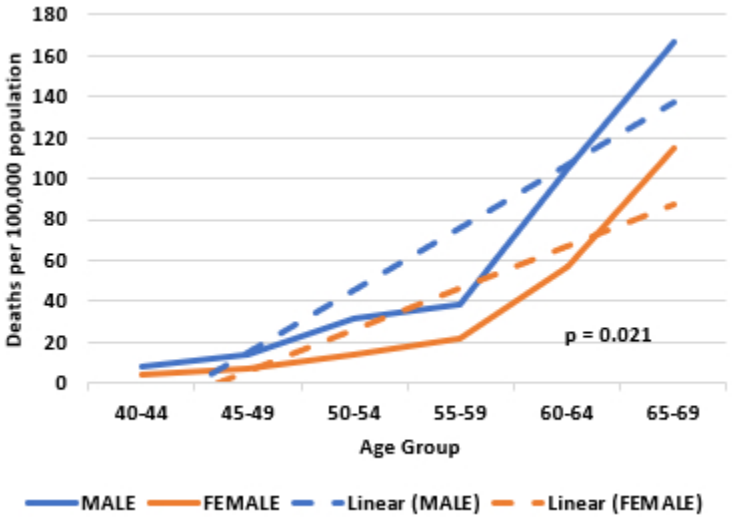

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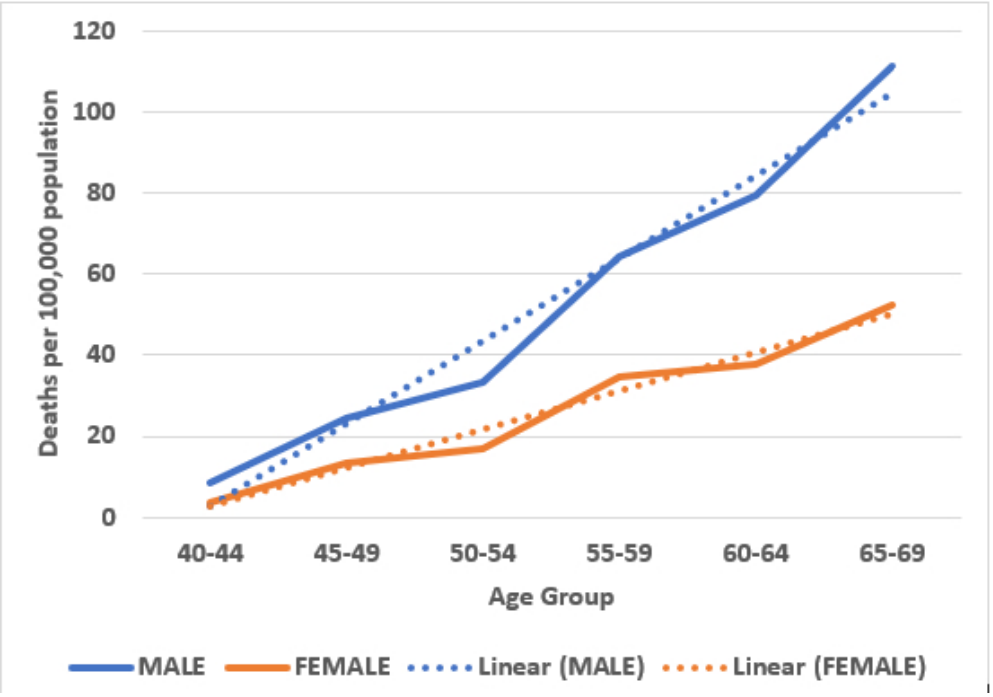

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Cardiovascular Mortality of 40–69-year-olds in Sri Lanka from 1980 -2010; a birth cohort analysis by age and sex

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Cardiovascular Mortality of 40–69-year-olds in Sri Lanka from 1980 - 2010; a birth cohort analysis by age and sex

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Abstract

Objectives

To compare cardiovascular mortality (ischaemic heart disease (IHD), hypertensive disease (HTN) and cerebrovascular disease (CeVD)) of 40–69-year-old Sri Lankans from 1980-2010 by age, birth cohort and sex.

Design

A comparative retrospective study.

Setting

Sri Lanka

Participants

40-69-year-old Sri Lankans from 1980-2010.

Primary and secondary outcome measures

Cardiovascular deaths due to IHD, HTN and CeVD.

Results

Mortality due to IHD increased with age but decreased with birth cohorts with time (range 3.7-390 per 100,000 population); there was a spike in the IHD mortality rates in both age-groups and birth cohorts in 2000. Deaths due to HTN markedly increased after 55 years; however, mortality decreased in the younger cohorts (range 2.8-204.81 per 100,000 population). CeVD mortality linearly increased with age (range 3.3-153.3 per 100,000 population); birth cohorts of 1926-1930 and

1931-1935 had a spike in mortality among 60-64 and 65-69 age groups, respectively. Changes were seen among both males and females; mortality rates were higher in males than in females.

Conclusions

All cardiovascular mortality rates increased with age and are higher in males than in females. Age specific cardiovascular mortality rates were lower in the younger birth cohorts as compared to the older birth cohorts. The increase in cardiovascular deaths in Sri Lanka is due to the ageing population.

Keywords: Cardiovascular mortality, 1980-2010, 40-69-year-olds, Sri Lanka

Strengths and limitations of this study

- Birth cohort analysis of mortality due to cardiovascular diseases by age and sex show trends in mortality and allows comparisons over time.
- Data used for the analysis have been published by the Registrar General's Department of Sri Lanka.
- Inability to determine the relationship between mortality and economic indicators due to lack of data is a limitation of the study.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally. They comprise a group of diseases of the heart and blood vessels including coronary heart disease (CHD), cerebrovascular disease (CeVD), peripheral artery disease, rheumatic heart disease, congenital heart disease, deep vein thrombosis and pulmonary embolism.[1]

In 2019, 17.9 million deaths due to CVDs accounting for 32% of all global deaths were estimated; 85% were due to heart attack and stroke. More than 75% of all CVD deaths occur in low- and middle-income countries; CVD deaths comprised 38% of premature deaths (under the age of 70) due to non-communicable diseases. [1]

Hypertension, a blood pressure above 140/90, is a leading risk factor for cardiovascular disease with a heavy public health burden worldwide. [2] Poorly controlled or uncontrolled blood pressure increases the risk of hypertensive disease (HTN) giving rise to microscopic and macroscopic cardiac remodeling and functional alterations.[3] It is estimated that 1.28 billion adults aged 30–79 years worldwide have hypertension with two-thirds living in low- and middle-income countries.[4] 46% of hypertensives are unaware they have the condition and less than 42% are diagnosed and treated; only 21% of adults with hypertension have it controlled.[4]

The number of CVD deaths has been increasing over time; in 2000, around 14 million died of CVDs globally, while in 2019, close to 18 million died.[5] CVD deaths are estimated to be >23 million by 2030.[6] The decline in incidence and mortality rates for developed countries was significantly higher than those for developing countries from 1990–2017 ($p < 0.05$); developing nations had a less-steeper decline.[7]

Risk factors for cardiovascular diseases include age, sex and other modifiable lifestyle risk factors.[7] The rising death toll is largely due to a growing and ageing global population. Death rates have been declining due to implementation of preventive programmes; large declines in smoking, improvements in screening, diagnosis, and monitoring; and advances in medical treatments, public health initiatives, emergency care, and surgical procedures have all helped to reduce the impact of cardiovascular diseases on people's lives.[7] The large disparities that still exist can be further reduced.

South Asia has a disproportionately high burden of cardiovascular disease, with higher rates of CVD incidence, mortality, and risk factor prevalences than many other regions.[8] CVDs account for 3.9 million deaths in the WHO South-East Asia Region every year, comprising a quarter of all deaths from non-communicable diseases (NCDs), with most of them being preventable.[9] Even though South Asians comprise only 25% of the world's population, they account for more than 50% of the world's cardiovascular deaths.[8]

Sri Lanka, a country having one of the fastest ageing populations in Asia, is in the midst of an epidemiological and demographic transition. In 2022, WHO estimated that over 80% of the mortality in Sri Lanka is due to major non-communicable diseases with CVDs contributing to over 34% of deaths, impacting both life expectancy and quality of life. The mortality from CVDs in Sri Lanka is estimated to be 524 deaths per 100,000 which is higher than that observed in many high-income countries. [10] Coronary artery disease (CAD) is the leading cause of death in Sri Lanka while stroke is the third highest cause of death. [11, 12]

Childhood risk factors such as obesity, exposure to indoor and outdoor tobacco smoke, dyslipidaemia and diabetes impact cardiovascular disease in adulthood[13] and are now being targeted for prevention of cardiovascular disease.

Birth cohort analyses have been used to determine the causal relationship between potential risk factors during the prenatal and postnatal period and the health status of the newborn up to childhood. Birth cohort analyses allow description of associations between early exposures and subsequent outcomes[14, 15]; in addition, they are able to identify the risk and environmental exposure factors shared by a given generation, are used to investigate disease trends and test a wide range of hypotheses. [14-17] Birth cohort analyses of CVDs have not been conducted in Sri Lanka. The aim of this study was to find out whether there are variations in age and sex specific mortality rates of selected CVDs (ischaemic heart disease, hypertensive disease and cerebrovascular disease) among 40-69-year-old Sri Lankans from 1980-2010 by birth cohort.

Methods

Study design and data sources

This comparative retrospective study was conducted from August 2022 to January 2024 using secondary data available in the public domain. Mortality data of Sri Lanka were extracted from the World Health Organization mortality database from 1980 through 2010 (country code 3365).[18] Mortality data are reported annually to the WHO from the civil registration system of the country (Registrar General's department). Mortality data included the number of deaths for 5-year age groups and coded as per the International Classification of Diseases (ICD) versions 9 (1979 up to

1992) and 10 (1993 to 2021). The 10th revision of the ICD was used in Sri Lanka from 1997 onwards.[19] Separate ICD codes are given for different causes of deaths falling under cardiovascular diseases. The ICD codes used for deaths due to ischaemic heart disease, hypertensive disease and cerebrovascular diseases in the 9th and 10th revisions used in this study are given in Supplementary Table 1.

For each disease category, deaths of 5-year age groups (40-44, 45-49, 50-54, 55-59, 60-64 and 65-69) were extracted from the database for the codes and subcodes given in Supplementary Table 1 from 1980 to 2010.

The birth cohorts for different age groups corresponding to the selected years of data extraction are given in Supplementary Table 2. For example, the age group 40-44 years in 1980 belonged to the 1936-1940 birth cohort. Likewise, the age group 65-69 years in 1980 belonged to the 1911-1915 birth cohort. For each birth cohort, the number of deaths for each group of ICD codes were summed for the age group studied. For example, for the birth cohort of 1936-1940, deaths coded as B27 (9th revision) were summed for the 40-44-year age group in 1980 (birth cohort of 1936-1940).

Mortality data from 1987 to 1995 were not available on the WHO website. Mortality data for 1990 was obtained by linear interpolation of the number of deaths separately for males and females in the different age groups considered. Mortality data by age and sex for 1995 were obtained from the Registrar General's Department, Sri Lanka.

Population data by age group and sex were obtained from the database displayed in the UN population website[21], Sri Lanka being coded as 144. Population data are displayed as estimates for inter-censal years as estimated by the Department of Census and Statistics of Sri Lanka and

reported to the UN; during the census years, the actual figures are provided. Population data are reported for 5-year age groups as done for mortality data by sex.

Extracted mortality and population data were tabulated to yield six, five-year age groups from 40–44 to 65–69 years, and seven quinquennial demographic profiles from 1980 to 2010 for the 12 birth cohorts.

Data analysis

Data were entered in Excel worksheets. Mortality rates for each of the three cardiovascular diseases for each age category of both sexes were calculated based on the following formula.

Mortality rate for each age-sex category = (deaths / population) * 100,000

Using the calculated mortality rates for each age group and birth cohort, trends were determined to identify birth cohort and age effects by sex. Data are presented as tables and graphs. Mortality rates of IHD, HTN and CeVD were plotted by age group, birth cohort and year by age and sex.

To compare sex differences in specific mortality rates of 40–70-year-old Sri Lankans from 1980-2010, mortality rates of the 1936-1940 birth cohort for which all age groups were included in the analyses were plotted against the age groups; using multiple regression analysis, the slopes of the regression lines using mortality rates as the dependent variable and age as the independent variable between males and females were compared.

Ethics statement

The Ethics Review Committee of the Faculty of Medicine, University of Kelaniya, Sri Lanka, exempted this study from ethics review (Ref No. P/149/11/2022).

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Results

The mortality rates due to ischaemic heart disease, hypertensive disease and cerebrovascular disease by age group, birth cohort and sex are given in Figures 1-6 and supplementary tables 3-5, respectively.

Insert figure 1 here

Mortality rates due to ischaemic heart disease increased with age among both males and females in each birth cohort (Figures 1 and 2, and Supplementary Table 3), the rates being higher in males than in females for each age group in each birth cohort each year. The mortality rates due to ischaemic heart disease for each age group was higher among the early birth cohorts as compared to the younger birth cohorts among both males and females. In each age group, the mortality rates of each birth cohort peaked corresponding to year 2000 in both males and females after which there is a progressive decline -in each subsequent birth cohort.

Insert figure 2 here

Similar to mortality rates due to ischaemic heart disease, mortality rates due to hypertensive disease increased with age among both males and females (Figures 3 and 4, and Supplementary Table 4); the mortality rates were higher in males than in females for each birth cohort and age group. The highest mortality rates due to hypertensive disease for each age group was higher among the early birth cohorts as compared to the later birth cohorts among both males and females, the rates being higher in males. Among both males and females, the mortality rates due to hypertensive disease of the 65-69 age group increased from the 1911-1915 to the 1941-1945 birth cohorts; spikes are seen in the mortality rates corresponding to year 2000. In the 1936-1940 birth cohort, the mortality rate due to hypertensive disease increased from 8.4 per 100,000 population in the 40-44-year age group to 167.1 per 100,000 population in the 65-69-year age group. Similar to the trends in ischaemic heart disease, a spike in the mortality rates due to hypertensive disease is seen in all birth cohorts in different age groups corresponding to year 2000.

Insert figures 3 and 4 here

Similar to ischaemic heart disease and hypertensive disease, mortality due to cerebrovascular disease (CeVD) increased with age among both males and females (Figures 5 and 6, and Supplementary Table 5) with the mortality rates being higher in males than in females for each birth cohort; the mortality rates due to CeVD for each age group was higher among the early birth cohorts as compared to the later birth cohorts among both males and females. Unlike the distinct spike in mortality rates due to ischaemic heart disease and hypertensive disease corresponding to year 2000 data, the spike for CeVD mortality rates was less marked. The mortality rates due to cerebrovascular diseases among males of the earlier cohorts for the older age groups (the 65-69 year age group of the 1926-1930 cohort and the 60-64 year age group of

the 1931-1935 cohort) peaked corresponding to year 1995 (Figure 6); among females, this peak was less distinct for the same year. In subsequent birth cohorts, the mortality rates have been declining for each age group.

Insert figures 5 and 6 here

Mortality rates due to IHD, HTN and CeVD among 40–69-year-old Sri Lankans of birth cohort 1936-1940 by sex are given in Supplemental figures 1-3, respectively. Mortality rates due to all three causes show an increasing trend in both sexes and the mortality rates of males being higher than that of females; there is a significant difference in the mortality rates for all three causes with age between males and females ($p<0.05$).

Discussion

The findings of this study show age, sex and 5-year birth cohort effects of selected cardiovascular deaths in 40-70-year-old Sri Lankans from 1980-2010. As expected, cardiovascular mortality rates due to IHD, HTN and CeVD increased with age; in each age group, mortality rates were higher among men. In the older age groups, the mortality rates due to HTN increased in the early cohorts till about year 2000; in the subsequent cohorts, age group mortality continued to decrease over time. CeVD mortality rates in males peaked in the older age groups (65-69 and 60-64) corresponding to year 1995 with a decline in younger cohorts and over time; among females, the trend was less marked. Although the number of deaths increased with time for different age groups due to an ageing population, the mortality rates decreased with each birth cohort.

An age-period-cohort study of CVD in Japan using data from 1995-2018 showed that mortality rates of both sexes increased with age[22], similar to what is reported here. The Japanese study also revealed an association between other co-morbidities with advancing age, such as diabetes mellitus, and atherosclerosis and age-related changes in the cardiovascular system such as reduced elasticity in blood vessels, increased arterial stiffness and hypertrophy of the heart etc. which could be probable causes for the higher mortality in older age.[22] Another Japanese study on mortality due to IHD from 1955 to 2000 showed non-linear birth cohort effects with an initial increase followed by a decreasing trend in both sexes.[16]

The findings of this study suggest that mortality rates due to HTN starts to rise after about 50 years of age. Again, there are birth cohort effects with younger cohorts having lower mortality rates with males having higher rates. [23] In Mexico, mortality due to hypertension affected more women than men; in the recent cohorts, the risk of dying from hypertension is two times higher in men compared to women. Hypertensive kidney disease was the main underlying cause, with an average increase throughout the study period.[23]

Similar to the trends of HTN, CeVDs, mortality rates are relatively constant in younger birth cohorts up to about 50 years. After 1985, there is a declining trend in mortality across the birth cohorts. Similar findings were reported from China where age-standardized stroke mortality rates started declining in every age group.[24] In Japan, age-standardized stroke morality rates per 100,000 population have declined from 98 in 1990, to 74 in 2000, to 50 in 2010, and to 33 in 2019 in males; among females, the decline was from 69 in 1990, to 46 in 2000, 27 in 2010, and to 18 in 2019. [25, 26]

In this study, the overall mortality rates of males are higher than that of females for all three cardiovascular diseases. Similar results were reported from southern Spain [27] and China.[28] The differences in mortality between males and females are partly due to biological differences including the protective effect of oestrogen in females; after menopause this effect gradually declines but the prevalences of other risk factors are lower than that of males. Other factors such as healthcare-seeking behaviour and social determinants also influence these differences. In Sri Lanka, females are subjected to routine screening at different ages during their lifetime from birth including antenatal and postnatal care clinics and well woman clinics; female attendance at healthy lifestyle centres where screening for CVD risk factors is done is much higher than that of males.

An interesting feature in this analysis is the spikes seen in mortality rates of all three cardiovascular deaths. For IHD and HTN the spikes correspond to data of year 2000; for CeVD the spike was less conspicuous. A possible reason for this observation is the change of the ICD coding system used from version 9 to 10 in 1997 despite ICD-10 being released in 1995[19]; ICD version 10 had more specific cause of death codes and had more causes of death for each disease which is likely to have increased the mortality rates for each cause of death. The subsequent decrease in the mortality rates may be due to the natural decrease in the mortality rates seen with successive birth cohorts.

Mortality rates of all three cardiovascular diseases considered show similar trends; like all non-communicable diseases, these disease entities share distinct common characteristics that are influenced by a broader range of lifestyle factors such as smoking, diet, physical activity, and obesity which have been targeted in preventive programmes.

Decline in mortality rates in successive birth cohorts may be due to many factors. Firstly, it may be due to differences in exposures *in utero*, childhood and even adulthood. Implementation of

screening programmes, and advances in medical and surgical procedures have contributed largely to early diagnosis and secondary prevention increasing the life expectancy of those diagnosed with cardiovascular diseases.[7] In addition, large declines in smoking due to increased public awareness and regulation, including heavy taxation, are now considered a "best buy" for reduction of cardiovascular disease.[7] Ma et al. (2008) suggested that lower mortality in younger birth cohorts in Japan was probably a result of improvements in lifestyle factors, including the national hypertension control prevention programme and improved nutrition in Japan during the previous few decades.[16] It is also likely to be due to improved economic status over time. The per capita GNI in Sri Lanka was current dollars 2510 in 1990; in 2010 it was 8150.

Over several decades the Sri Lanka's health system has improved tremendously in all aspects achieving impressive health indicators comparable to those of developed countries but at a much lower cost. This achievement is attributable to an excellent preventive health service originally initiated in 1926; though initially concentrating on maternal and child health, the service has been extended to cover environmental health and later to non-communicable diseases after the inclusion of prevention and control of non-communicable diseases in the first national health policy based on primary health care, and subsequently revised with a focus on universal health coverage.[29] Simultaneously, clinical services were improved and expanded with an increase in the number of hospital beds, advancements in technology and other related services. The number of doctors per 10,000 population has increased from 1401 in 1991 to 11,924 in 2021[30]. Initially, general physicians in medical wards treated cardiology patients; subsequently since the early 1970's cardiology as a specialty emerged in Sri Lanka. Specialisation in cardiology and cardiothoracic surgery followed and special units were created; in the public sector in 2020, there were 644 inward beds for cardiology compared to 470 in 2008 [31, 32]. The improvement and expansion of healthcare

services and the emergence of cardiology as a specialty beginning in the 1970's probably explains the high mortality rates in older age groups of early cohorts.

In Sri Lanka, preventative activities carried out by the Ministry of Health at national level are likely to have contributed to improvements in cardiovascular health among the younger generations: these include, tobacco control measures (both policy and legislation); nutrition and food policies to address obesity and high lipid levels; and health promotion to raise awareness about the importance of cardiovascular health and the prevention of CVDs.[33]

Limitations

Data for 1990 and 2008 were not available and data were interpolated separately for males and females. The fact that the validity of our results is dependent on the accuracy and reliability of mortality data and the vital statistics registration system of the country is acknowledged. Studies have reported that cause of death certification is not 100% accurate, as expected. [34, 35] However, given the CVD causes of death that were investigated it is unlikely to have adversely impacted on our results; the rates were calculated based on large denominators that would have little or no effect on the overall mortality rates.

Relating the differences in mortality rates to economic indicators was not attempted. The GNI was available from 1990 onwards and requires a more detailed analysis that should be conducted in the future.

Conclusions

There are age, period and birth cohort effects on mortality due to IHD, HTN and CeVD among 40-70-year-old male and female Sri Lankans between 1980 and 2010. Mortality increased with

age and declined in younger cohorts over time as compared to older cohorts. Males had higher mortality rates than females for each age group in each birth cohort.

It is likely that age-sex specific mortality rates due to cardiovascular diseases will decline further, but at a much lower rate, provided that prevention and control measures for CVD risk factors are enhanced and sustained; however, the number of deaths due to cardiovascular diseases will increase due to the increasing ageing population for which adequate care facilities should be improved, expanded and provided.

Contributors

DTHDeS, EDSMDeA, DMDeM, AHDDeS and ARW contributed to the conceptualisation and developing the methodology. ARW supervised data collection. All authors were involved in data curation, data analysis, writing the original draft, and reviewing and editing the final draft. ARW is the guarantor and accepts full responsibility for the work and conduct of the study.

Funding

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Competing interests

All authors have no competing interests to declare.

Patient and public involvement

Patients and the public were not specifically involved in the design, conduct, reporting or dissemination plans of our research.

Data availability statement

All data extracted are given in the supplementary tables and in the tables.

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Figure legends

Figure 1. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a_1-mortality rates by age for different birth cohorts among males; panel a_2-mortality rates by birth cohorts for different age groups among males; panel b_1-mortality rates by age for different birth cohorts among females; panel b_2-mortality rates by birth cohorts for different age groups among females)

Figure 2. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 3. Mortality rates due to Hypertensive disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a_1-mortality rates by age for different birth cohorts in males; panel a_2-mortality rates by birth cohorts for different age groups in males; panel b_1-mortality rates by age for different birth cohorts in females; panel b_2-mortality rates by birth cohorts for different age groups in females)

Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Figure 5. Mortality rates due to Cerebrovascular disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a_1-mortality rates by age for different birth cohorts in males; panel a_2-mortality rates by birth cohorts for different age groups in males; panel b_1-mortality rates by age for different birth cohorts in females; panel b_2-mortality by birth cohorts for different age groups in females)

Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

Supplemental figure 1. Sex differences in mortality rates due to IHD by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 2. Sex differences in mortality rates due to HTN by age group in males and females of the 1936-1940 birth cohort.

Supplemental figure 3. Sex differences in mortality rates due to CeVD by age group in males and females of the 1936-1940 birth cohort.

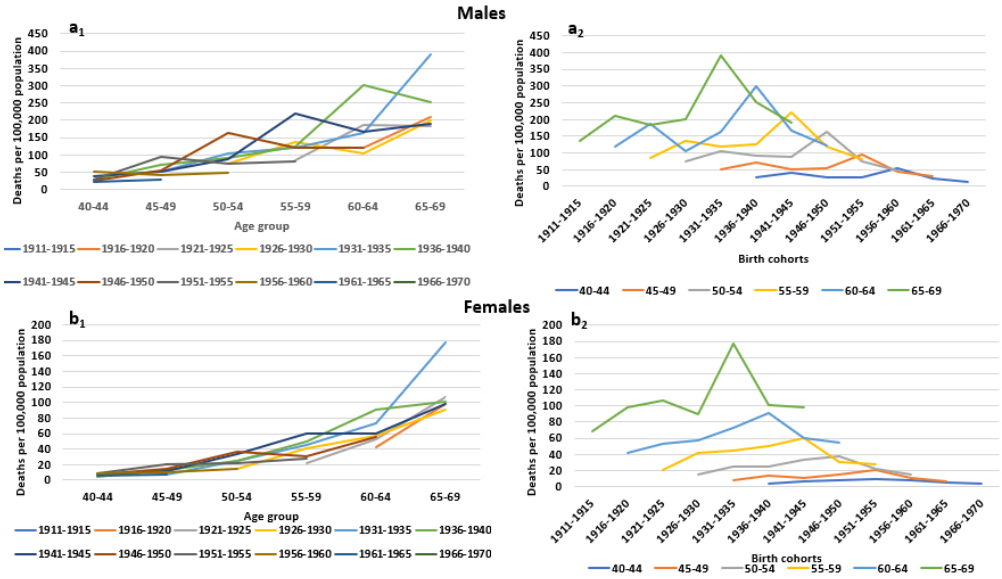


Figure 1. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts among males; panel a2-mortality rates by birth cohorts for different age groups among males; panel b1-mortality rates by age for different birth cohorts among females; panel b2-mortality rates by birth cohorts for different age groups among females)

586x342mm (38 x 38 DPI)

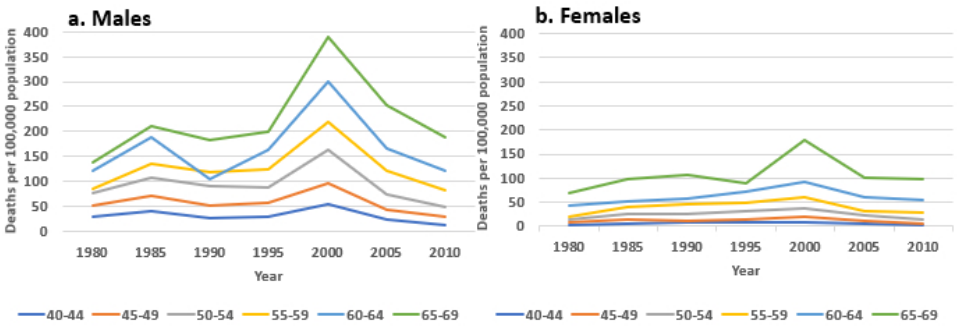


Figure 2. Mortality rates due to Ischaemic Heart disease among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

479x166mm (38 x 38 DPI)

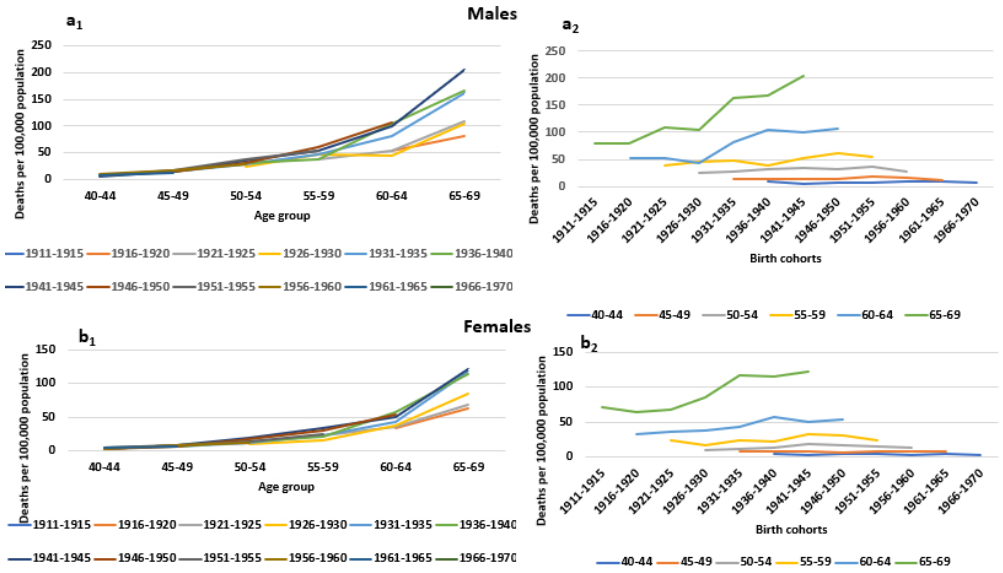


Figure 3. Mortality rates due to Hypertensive disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality rates by birth cohorts for different age groups in females)

544x312mm (38 x 38 DPI)

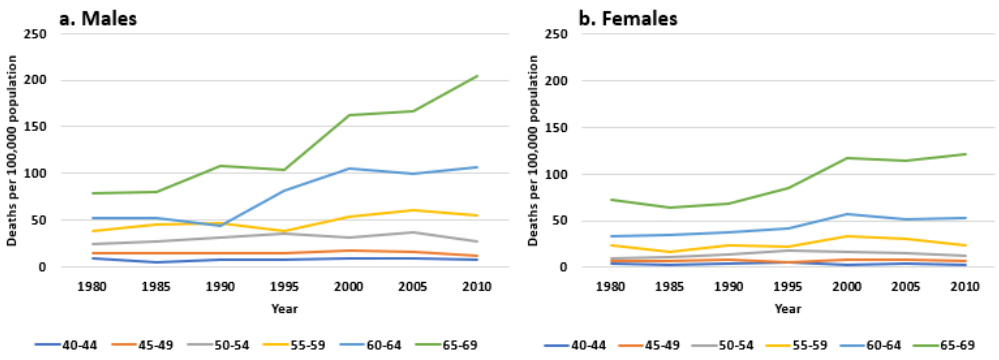


Figure 4. Mortality rates due to Hypertensive Disease (HTN) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

512x192mm (38 x 38 DPI)

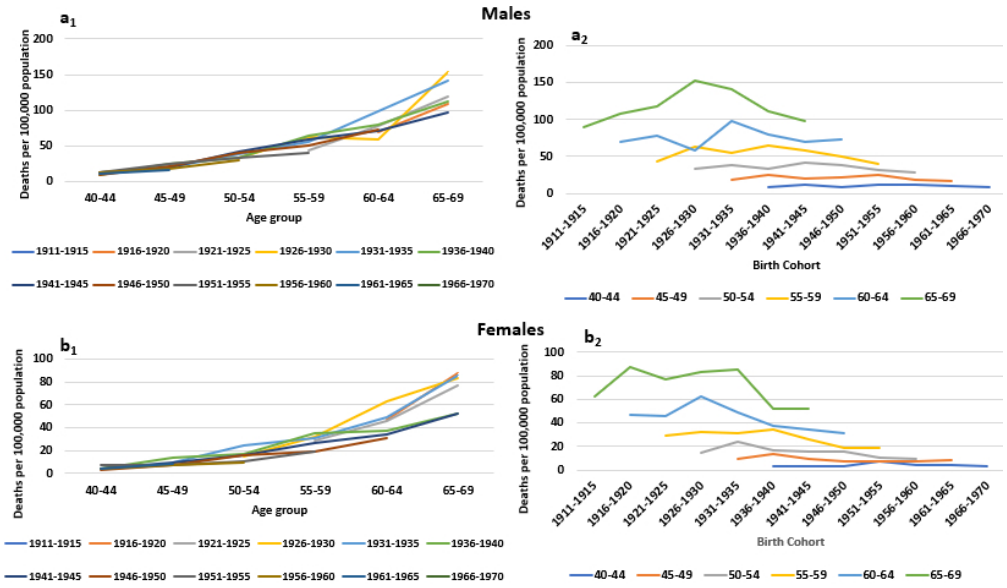


Figure 5. Mortality rates due to Cerebrovascular disease among 40-69-year-old Sri Lankans by age groups, birth cohort and sex. (panel a1-mortality rates by age for different birth cohorts in males; panel a2-mortality rates by birth cohorts for different age groups in males; panel b1-mortality rates by age for different birth cohorts in females; panel b2-mortality by birth cohorts for different age groups in females)

546x316mm (38 x 38 DPI)

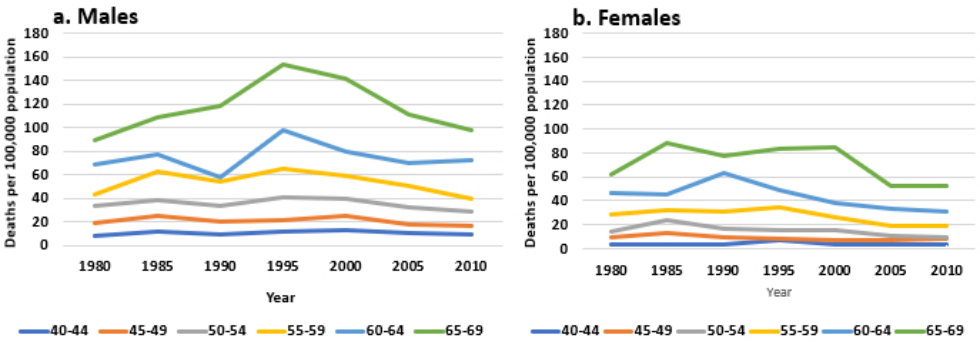


Figure 6. Mortality rates due to Cerebrovascular disease (CeVD) among 40-69-year-old Sri Lankans by year by age groups and sex. (panel a- for males; panel b for females)

468x171mm (38 x 38 DPI)

Supplementary Table 1. Cause of death codes of selected conditions of the International Classification of Diseases versions 9 and 10

Cause of death	ICD-9		ICD-10	
	Code	**Subcode**	**Code**	**Subcode**
Ischaemic Heart Disease	B27		1067	I20-I25
Acute myocardial infarction		B270		I21
Remainder		B279		I20, I22, I23, I24, I25
Hypertensive Disease	B26		1066	I10-I13
Hypertensive heart disease		B260		I11
Remainder		B269		I10, I12, I13
Cerebrovascular disease	B29		1069	I60-I69
Subarachnoid hemorrhage		B290		I60
Intracerebral and other intracranial hemorrhage		B291		I61
Cerebral infarction		B292		I63
Others		B293, B294, B299		I62, I64-I69

Source: WHO. Mortality database[20]

Supplementary Table 2. Birth cohorts corresponding to different age groups 1980-2010

Age Group	Year						
	1980	1985	1990	1995	2000	2005	2010
40-44	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
45-49	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965
50-54	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960
55-59	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955
60-64	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950
65-69	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945

Supplementary Table 3. Deaths due to Ischaemic Heart Disease per 100,000 population in Sri Lanka by birth cohort and age group

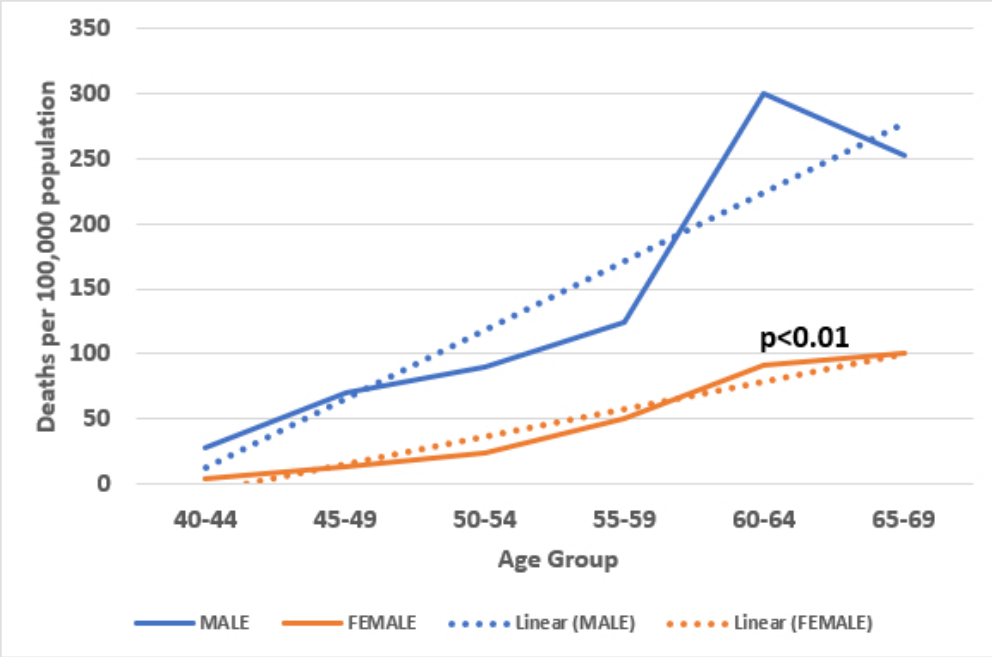
Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						28.42	40.02	25.58	28.23	52.84	23.41	13.03
45-49					51.52	70.20	50.26	55.83	96.02	42.97	28.85	
50-54				75.26	105.89	90.60	87.68	164.23	73.50	47.65		
55-59			85.97	135.67	119.64	124.77	219.60	120.39	81.31			
60-64		120.35	187.19	104.35	163.57	300.37	167.23	122.23				
65-69	136.73	210.55	182.50	199.57	389.99	252.12	189.32					
Females												
40-44						3.77	6.77	7.53	9.22	8.68	5.86	3.71
45-49					7.76	12.95	11.28	14.97	20.53	10.41	6.91	
50-54				14.87	25.59	24.69	33.07	37.18	22.29	15.02		
55-59			21.37	41.48	45.29	50.24	60.21	30.40	27.42			
60-64		42.14	53.13	57.32	72.83	91.09	59.50	55.25				
65-69	68.17	98.12	106.77	90.38	177.83	100.98	97.80					

Supplementary Table 4. Deaths due to Hypertensive Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	4.23	7.40	7.44	8.81	8.61	7.04
45-49					14.40	14.28	15.03	14.34	17.48	15.63	12.39	
50-54				24.28	27.24	31.35	35.23	31.63	36.95	27.15		
55-59			38.21	45.84	46.91	38.24	53.28	60.80	54.55			
60-64		52.62	52.80	44.06	82.18	105.20	99.89	106.07				
65-69	78.76	80.00	108.50	104.23	162.42	167.07	204.82					
Females												
40-44						4.06	2.51	3.77	4.71	2.95	3.81	2.28
45-49					7.08	7.23	7.95	5.77	8.13	7.65	7.06	
50-54				9.53	11.57	13.58	18.37	17.16	14.55	12.60		
55-59			23.64	16.35	23.19	21.62	33.36	29.96	23.93			
60-64		33.36	35.26	38.08	42.27	57.18	50.96	53.51				
65-69	71.96	63.49	68.23	85.46	116.66	114.62	121.64					

Supplementary Table 5. Deaths due to Cerebrovascular Disease per 100,000 population in Sri Lanka by birth cohort and age group

Age group (years)	Year											
	1911-1915	1916-1920	1921-1925	1926-1930	1931-1935	1936-1940	1941-1945	1946-1950	1951-1955	1956-1960	1961-1965	1966-1970
Males												
40-44						8.44	12.18	8.67	11.63	12.29	10.12	8.84
45-49					18.88	24.39	19.69	21.18	24.51	17.83	16.46	
50-54				32.95	38.48	33.54	41.24	39.13	32.11	28.73		
55-59			43.39	62.99	54.55	64.40	58.58	50.67	39.23			
60-64		69.19	77.67	57.97	98.14	79.55	70.24	72.48				
65-69	89.47	108.33	118.50	153.30	141.01	111.52	97.43					
Females												
40-44						3.48	3.51	3.35	7.34	3.93	3.81	3.42
45-49					9.10	13.55	9.49	7.70	7.36	7.65	7.94	
50-54				14.49	23.84	16.98	16.01	15.84	10.39	8.88		
55-59			29.10	31.91	30.80	34.66	26.04	18.81	18.59			
60-64		46.82	45.41	62.76	49.44	37.56	33.88	31.01				
65-69	62.11	87.86	77.08	83.67	85.07	52.33	52.26					



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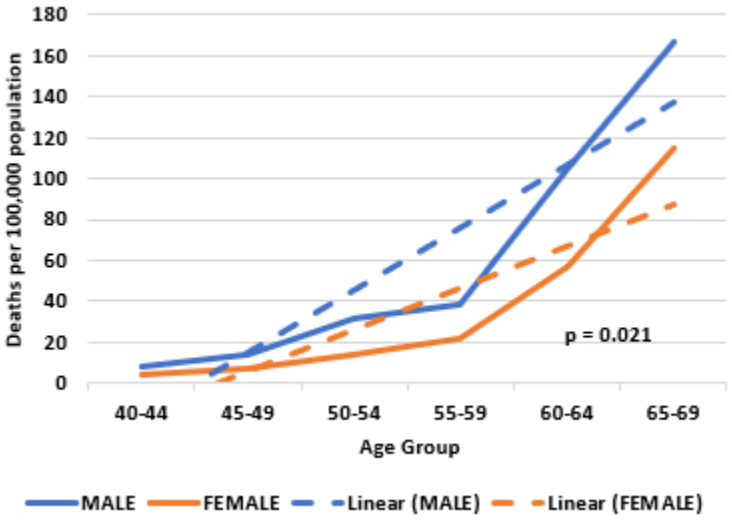

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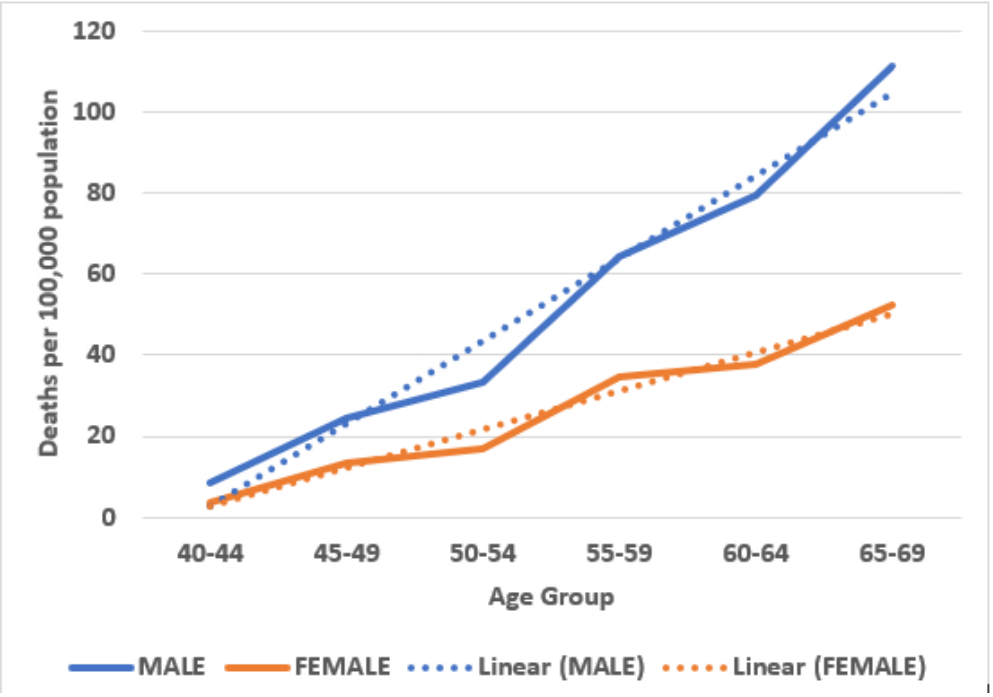

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