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Evolution of Glaucoma-Related Mortality among Older Adults in the United States: Insights from CDC WONDER (2000–2023)

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Abstract

Glaucoma is a common optic neuropathy in older U.S. adults, yet its national temporal mortality trends have not been elucidated. This study examines glaucoma-related trends and disparities in mortality among older adults, promoting awareness of ophthalmic health inequities. Death certificates from the Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiologic Research (CDC WONDER) database were analyzed among adults aged ≥ 65 years with glaucoma-related deaths from 2000 to 2023. Crude mortality rates (CMRs) and age-adjusted mortality rates (AAMRs) per 100,000 were calculated and stratified by demographics and geography. Trends in annual percent change (APC) and average APC were assessed using Jointpoint regression with 95% confidence intervals. A total of 21,805 glaucoma-related deaths occurred in older adults from 2000 to 2023. AAMRs declined initially from 2.98 in 2000 to 1.80 in 2009 (APC: -6.01; 95% CI: -10.46 to -4.53), followed by stable rates until 2023. Mortality rates were highest in adults aged ≥ 85 years, men, non-Hispanic (NH) Black/African Americans, residents of non-metropolitan areas, and Midwestern regions. Heart disease was the leading underlying cause of glaucoma-associated death, with COVID-19 playing a major role from 2000 to 2023. Glaucoma-related mortality in older adults rose with notable risks among adults aged ≥ 85 years, men, NH Black/African Americans, residents in non-metropolitan areas, and the Midwest. These findings call for targeted, informed public health interventions to ameliorate outcomes.

1.0 INTRODUCTION

Glaucoma is a chronic, progressive optic neuropathy disorder characterized by irreversible damage to the optic nerve, which results in visual field loss and blindness if untreated [1]. It is among the leading causes of irreversible blindness worldwide, affecting nearly 76 million people in 2020, and the number is projected to rise to 111.8 million by 2040, with around two-thirds of all glaucoma cases above 70 years of age [2, 3]. The disease burden grows exponentially with advancing age, and population aging has therefore become a major driver of global glaucoma prevalence and associated disability [4].

Rising research has highlighted the possibility of glaucoma having more systemic risks than just visual side effects [5]. While glaucoma is usually not a cause of death, it does have associations with age-related vascular, metabolic, and neurodegenerative conditions. Having visual impairment can cause more falls, cognitive decline, and reduced quality of life, which can affect long-term morbidity and mortality, especially in elderly subjects [6]. By examining patterns of glaucoma mortality, we could gain a better understanding of both ocular and other health inequalities in aging populations.

In the United States, glaucoma and its impact are distributed unevenly across racial, demographic, and geographic sub-groups [7]. These inequities are also due to socioeconomic factors, unequal access to quality health care, or differing patterns of health-seeking behaviors. Still, there is a lack of national-level analysis of glaucoma-related deaths, as most studies look at the prevalence, disparities in treatment, or visual impairment only. There is limited available research that has examined temporal mortality trends,

with stratifications by demographic or regional classifications, or the impact of recent system disruptions such as COVID-19.

Population-based data is essential for tracking mortality trends. This information helps us understand the long-term burden of disease. We used the Centers for Disease Control and Prevention (CDC) Wide-ranging Online Data for Epidemiologic Research (WONDER) database to examine glaucoma-specific mortality trends over several decades [8].

This study explores trends and differences in glaucoma mortality among U.S. adults aged 65 and older from 2000 to 2023. It includes estimates of age-adjusted mortality rates for both the overall population and specific subgroups.

2.0 METHODS

2.1 Study Design and Data Source

In this population-based analysis, death certificate data were retrieved from the CDC WONDER (Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiologic Research) database. Death certificate data from 2000 to 2023 for glaucoma-related mortality in adults aged ≥ 65 years was examined using codes from the International Statistical Classification of Diseases and Related Health Problems-10th Revision (ICD-10) specified as H40. This dataset includes cause of death from death certificates for the 50 states and the District of Columbia and has been previously used in several studies to determine trends in mortality [9]. The Multiple Cause-of-Death Public Use record death certificates were studied to select Glaucoma-related deaths, which were identified as those with glaucoma reported anywhere on the death certificate, either as a contributing or underlying cause of death. Additionally, extraction for the leading causes of glaucoma-associated deaths using the top 15 underlying causes of death (UCD-15) list from CDC WONDER was divided into pre-pandemic (2000–2019) and pandemic (2020–2023) time periods, with their respective ICD-10 codes (Supplemental Table S1). Older adults were defined as adults aged ≥ 65 years. Age groups were stratified into three categories: adults aged 65–74 years, 75–84 years, and ≥ 85 years. Similar age group classifications have been used to define older adults in previous studies [10, 11]. This study was exempt from local institutional review board approval as it utilized de-identified, government-issued public use records. We followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for reporting [12].

2.2 Variables and Measures

Data for population size, year, location of death, demographics, urbanicity, U.S. census region, state, and leading underlying causes of glaucoma-associated deaths were extracted and analyzed. Place of death included medical facilities (inpatient, outpatient/emergency room, death on arrival, or status unknown), decedent’s home, hospices, nursing home/long-term care facility, other, and unknown locations. Demographic grouping included sex, age group, and race (non-Hispanic (NH) White, NH Black or African

American, and Hispanic or Latino). The Urban-Rural Classification Scheme from the National Center for Health Statistics was used to evaluate the population by metropolitan (large metropolitan area [population ≥ 1 million], medium/small metropolitan area [population between 50,000 and 999,999]) and non-metropolitan (population under 50,000) counties based on the 2013 U.S. census classification [13]. U.S. census regions were classified into the Northeast, Midwest, South, and West in line with the U.S. Census Bureau definitions.

2.3 Statistical Analysis

To examine national trends in glaucoma-related mortality, we calculated crude mortality rates (CMRs) and age-adjusted mortality rates (AAMRs) per 100,000 persons by standardizing glaucoma-related deaths to the year 2000 U.S. population [14]. CMRs and AAMRs from death certificates were extracted from 2000 to 2023 and stratified by year, sex, race, state, and urban-rural status with corresponding 95% CIs. AAMRs were calculated by standardizing glaucoma-related deaths to the year 2000 U.S. population. To quantify national annual trends in glaucoma-related mortality, the Joinpoint Regression Program (National Cancer Institute, version 5.0) was used to determine the annual percent change (APC) and average annual percent change (AAPC) with 95% CI in AAMR [15]. This method identifies significant changes in AAMR over time by fitting log-linear regression models where temporal variation occurred. A value of $p < 0.05$ was considered statistically significant.

3.0 RESULTS

A total of 21,805 glaucoma-related deaths occurred among adults aged ≥ 65 years from 2000 to 2023 in the United States. Most deaths occurred in nursing homes/long-term care centers (10,216; 46.85%), followed by the decedent's home (4,865; 22.31%) and medical facilities (4,828; 22.14%). Smaller proportions of deaths occurred in hospices (699; 3.21%) and other/unknown locations (1,197; 5.49%) (Fig. 1; Supplemental Table S2).

3.1 Annual Trends

Overall AAMRs declined from 2.98 (95% CI: 2.80–3.16) in 2000 to 2.29 (95% CI: 2.16–2.42) in 2023 (AAPC: -1.39; 95% CI: -1.88 to -0.92). AAMRs initially decreased from 2000 to 2009 (APC: -6.01; 95% CI: -10.46 to -4.53), followed by stable rates from 2009 to 2016. Mortality rates increased afterwards until 2023 (APC: 5.36; 95% CI: 2.86 to 10.91) (Fig. 2; Supplemental Tables S3 and S4).

3.2 Sex-Specific Trends

Women accounted for 13,738 deaths (63%), while men accounted for 8,067 deaths (37%). The average AAMR was similar for women and men (average AAMR women: 2.08; average AAMR men: 2.09).

AAMRs for women declined from 3.00 (95% CI: 2.78–3.23) in 2000 to 2.21 (95% CI: 2.05–2.38) in 2023 (AAPC: -1.57; 95% CI: -2.17 to -1.01). AAMRs initially decreased from 2000 to 2010 (APC: -5.84; 95% CI:

-10.80 to -0.23), followed by stable rates until 2023.

AAMRs for men declined from 2.97 (95% CI: 2.66–3.29) in 2000 to 2.37 (95% CI: 2.16–2.58) in 2023 (AAPC: -1.09; 95% CI: -1.59 to -0.53). AAMRs initially decreased from 2000 to 2009 (APC: -5.71; 95% CI: -11.25 to -2.68), followed by stable rates from 2009 to 2015. Mortality rates then increased afterwards until 2023 (APC: 5.01; 95% CI: 0.41 to 10.53). (Fig. 2; Supplemental Tables S3 and S4).

3.3 Race Specific Trends

Non-Hispanic (NH) Whites had the greatest number of deaths, 16,945 (79.81%), followed by NH Black/African Americans 3,182 (14.98%) and Hispanic/Latinos 1,105 (5.20%). In terms of AAMR, NH Black/African Americans had the highest average AAMR (3.92), followed by NH Whites (1.99) and Hispanic/Latinos (1.61).

NH Black/African Americans had their AAMRs decrease from 5.83 (95% CI: 4.90–6.75) in 2000 to 4.15 (95% CI: 3.54–4.75) in 2023 (AAPC: -1.17; 95% CI: -2.17 to -0.12). AAMRs initially decreased from 2000 to 2014 (APC: -5.55; 95% CI: -8.87 to -3.69), followed by an increase in rates until 2023 (APC: 6.05; 95% CI: 2.56 to 14.61).

NH Whites had their AAMRs decrease from 2.87 (95% CI: 2.68–3.06) in 2000 to 2.17 (95% CI: 2.03–2.32) in 2023 (AAPC: -1.39; 95% CI: -1.74 to -1.05). AAMRs initially decreased from 2000 to 2010 (APC: -5.89; 95% CI: -8.03 to -5.07), followed by stable rates from 2010 to 2016. Mortality rates then increased afterwards until 2023 (APC: 5.15; 95% CI: 3.63 to 9.02).

AAMRs for Hispanic/Latinos remained stable from 1.73 (95% CI: 1.10–2.59) in 2000 to 2.27 (95% CI: 1.83–2.71) in 2023, with no increases or decreases in mortality rates interspersed throughout the study duration. (Fig. 3; Supplemental Tables S4 and S5).

3.4 Age Group Specific Trends

Adults aged ≥ 85 years contributed the greatest number of deaths (14,389) and the highest average CMR (10.98), followed by adults aged 75–84 years (5,503 deaths; average CMR: 1.64) and 65–74 years (1,913 deaths; average CMR: 0.33).

CMRs for adults aged 65–74 years remained stable from 0.53 (95% CI: 0.43–0.65) in 2000 to 0.37 (95% CI: 0.31–0.43) in 2023. CMRs initially decreased from 2000 to 2015 (APC: -5.19; 95% CI: -7.33 to -3.67), followed by an increase in rates until 2023 (APC: 8.15; 95% CI: 4.62 to 14.45).

CMRs for adults aged 75–84 years decreased from 2.54 (95% CI: 2.26–2.82) in 2000 to 1.64 (95% CI: 1.45–1.82) in 2023 (AAPC: -1.83; 95% CI: -2.26 to -1.37). CMRs initially decreased from 2000 to 2014 (APC: -5.10; 95% CI: -6.09 to -4.31), followed by an increase in rates until 2023 (APC: 3.49; 95% CI: 1.90 to 5.84).

CMRs for adults aged ≥ 85 years declined from 14.91 (95% CI: 13.74–16.07) in 2000 to 12.33 (95% CI: 11.46–13.21) in 2023 (AAPC: -1.30; 95% CI: -1.82 to -0.79). CMRs initially decreased from 2000 to 2010 (APC: -5.78; 95% CI: -10.09 to -1.95), followed by stable rates from 2010 to 2016. Mortality rates then increased afterwards until 2023 (APC: 4.80; 95% CI: 1.85 to 11.07) (Fig. 4; Supplemental Tables S4 and S6).

3.5 Urbanization-Specific Trends (2000–2020)

Although metropolitan areas accounted for most of the deaths (14,698), average AAMRs were higher in non-metropolitan (2.39) compared with metropolitan (2.02) areas.

AAMRs for non-metropolitan areas declined from 3.45 (95% CI: 3.01–3.89) in 2000 to 2.33 (95% CI: 2.01–2.65) in 2020 (AAPC: -2.74; 95% CI: -3.84 to -1.96). AAMRs initially decreased from 2000 to 2015 (APC: -5.27; 95% CI: -7.53 to -4.32), followed by stable rates until 2020.

Metropolitan areas had their AAMRs decline from 2.89 (95% CI: 2.69–3.09) in 2000 to 2.16 (95% CI: 2.03–2.30) in 2020 (AAPC: -2.09; 95% CI: -2.69 to -1.59). AAMRs initially decreased from 2000 to 2009 (APC: -6.35; 95% CI: -10.16 to -4.81), followed by stable rates from 2009 to 2016. Mortality rates then increased afterwards until 2020 (APC: 6.34; 95% CI: 2.15 to 14.07) (Fig. 5; Supplemental Tables S4 and S7).

3.6 Region-Specific Trends

The Midwest had the highest number of deaths (5,562) and the greatest average AAMR (2.36), followed by the Northeast (4,864 deaths; average AAMR: 2.22), West (4,661 deaths; average AAMR: 2.09), and South (6,718 deaths; average AAMR: 1.84).

In the Northeast, AAMRs remained stable over the study period, from 2.88 (95% CI: 2.50–3.26) in 2000 to 3.19 (95% CI: 2.84–3.54) in 2023. AAMRs initially decreased from 2000 to 2008 (APC: -7.19; 95% CI: -10.4361 to -4.9079), followed by increasing rates from 2008 to 2013 (APC: 6.41; 95% CI: 0.87 to 15.96). Mortality rates then decreased again from 2013 to 2016 (APC: -10.11; 95% CI: -15.35 to -1.17), followed by another increase in rates from 2016 to 2020 (APC: 16.03; 95% CI: 10.96 to 25.42) and lastly stable rates until 2023.

In the Midwest, AAMRs declined from 3.79 (95% CI: 3.38–4.20) in 2000 to 1.37 (95% CI: 1.15–1.59) in 2023 (AAPC: -4.33; 95% CI: -5.15 to -3.61). AAMRs initially decreased from 2000 to 2014 (APC: -6.32; 95% CI: -8.99 to -5.30), followed by stable rates until 2023.

In the South, AAMRs declined from 2.77 (95% CI: 2.47–3.07) in 2000 to 2.21 (95% CI: 2.00–2.42) in 2023 (AAPC: -1.33; 95% CI: -2.08 to -0.62). AAMRs initially decreased from 2000 to 2010 (APC: -6.69; 95% CI: -13.48 to -3.78), followed by stable rates from 2010 to 2018, and lastly increasing rates thereafter until 2023 (APC: 8.75; 95% CI: 3.44 to 19.97).

In the West, AAMRs remained stable, from 2.55 (95% CI: 2.17–2.93) in 2000 to 2.48 (95% CI: 2.19–2.76). AAMRs were initially stable from 2000 to 2010, followed by increasing mortality rates thereafter until 2023 (APC: 3.79; 95% CI: 2.69 to 5.01) (Fig. 6; Supplemental Tables S4 and S8).

3.7 Leading Underlying Causes of Death (2000–2019)

From 2000 to 2019, the top 5 leading underlying causes of glaucoma-associated deaths were heart disease, malignant neoplasms, Alzheimer's disease, cerebrovascular diseases, and chronic lower respiratory diseases. Heart disease resulted in 4,000 deaths with an AAMR of 0.44 (95% CI: 0.42–0.45), followed by malignant neoplasms with 2,730 deaths and an AAMR of 0.33 (95% CI: 0.32–0.34). Alzheimer's disease accounted for 1,702 deaths (AAMR: 0.18; 95% CI: 0.17–0.19), and cerebrovascular diseases caused 1,413 deaths (AAMR: 0.15; 95% CI: 0.14–0.15). Chronic lower respiratory diseases and diabetes mellitus each contributed 808 and 796 deaths, respectively, both with an AAMR of 0.08. Other notable causes included essential hypertension and hypertensive renal disease (687 deaths; AAMR: 0.06), unintentional injuries (348 deaths; AAMR: 0.02), Parkinson's disease (345 deaths; AAMR: 0.06), influenza and pneumonia (196 deaths; AAMR: 0.01), pneumonitis due to solids and liquids (105 deaths; AAMR: 0.01), in situ/benign/uncertain or unknown behavior neoplasms (103 deaths; AAMR: 0.01), sepsis (85 deaths; AAMR: 0.01), nephritis/nephrotic syndrome/nephrosis (82 deaths; AAMR: 0.01), and anemias (61 deaths; AAMR: 0.00) (Fig. 7; Supplemental Tables S9 and S10).

3.8 Leading Underlying Causes of Death (2020–2023)

From 2020 to 2023, the top 5 leading underlying causes of glaucoma-associated deaths included heart disease, malignant neoplasms, Alzheimer's disease, cerebrovascular diseases, and COVID-19. Heart disease accounted for 793 deaths with an AAMR of 0.34 (95% CI: 0.32–0.37), followed by malignant neoplasms with 643 deaths and an AAMR of 0.31 (95% CI: 0.28–0.33). Alzheimer's disease resulted in 398 deaths (AAMR: 0.18; 95% CI: 0.16–0.20), while cerebrovascular diseases caused 282 deaths (AAMR: 0.13; 95% CI: 0.12–0.15). COVID-19 contributed to 276 deaths with an AAMR of 0.12 (95% CI: 0.11–0.14). Other notable causes included diabetes mellitus (199 deaths; AAMR: 0.07; 95% CI: 0.06–0.08), chronic lower respiratory diseases (172 deaths; AAMR: 0.08; 95% CI: 0.07–0.10), and essential hypertension and hypertensive renal disease (162 deaths; AAMR: 0.06; 95% CI: 0.05–0.07). Remaining causes, such as unintentional injuries, Parkinson's disease, nutritional deficiencies, influenza and pneumonia, septicemia, chronic liver disease, and in situ/benign/uncertain or unknown behavior neoplasms, accounted for fewer deaths with corresponding lower AAMRs (Fig. 8; Supplemental Tables S9 and S10).

4.0 DISCUSSION

Glaucoma mortality among older US adults spanning more than two decades was dynamic, with a decrease in the early 2000s, relative stabilization over the next decade, and a foreboding spike after 2016. These trends are also reflected in worldwide reports of initial progress through mass screening, new pharmacologic therapy, and improved surgical technique, followed by plateauing of these advances

in high-resource nations. The later rebound is concurrent with aging populations, increasing systemic comorbidities like diabetes and vascular disease, and persisting disparities in access to specialty care [16, 17]. By examining the CDC WONDER national mortality data and Joinpoint regression, it is revealed that while earlier there was improvement, sex, race, age, urbanization, and geographic disparities still characterize the burden of glaucoma mortality in the United States.

The broad trend of early declines ultimately reversed to increases, capturing the interplay between medical innovation and population health forces. Death decreased with improvements in cataract and glaucoma surgery, the introduction of prostaglandin analogues, and access to eye exams due to factors related to Medicare. As treatment becomes commonplace, innovation stalls, and population condition and demographic pressures once more catch up with deaths. Post-2016 increase in later rise also aligns with wider literature that indicates multimorbidity, frailty, and demographically driven aging are transforming ophthalmic results as a systemic disease concern rather than as an isolated ocular disease. [18]. In the post-2020 period, an additional finding was the emergence of COVID-19 as a significant co-occurring and contributing cause of glaucoma-associated deaths, reflecting the systemic vulnerability of elderly adults with ocular and vascular comorbidities.

Sex trends were also noticed to be relatively evenly balanced during the study duration, where men and women both declined and then rose, and had similar average AAMRs. This concordance agrees with other US and European studies that found there were few sex-specific differences in glaucoma progression after controlling for age and comorbidity [19, 20]. Underneath this, there are differences in behavior and care-seeking. Preventive eye care in the past has been accessed more by women, allowing earlier detection, while more surgical intervention was performed in men, including for more advanced disease. With increasing access to health care becoming increasingly equal between the two sexes with the passage of time, mortality convergence occurred. Late acceleration in both sexes follows evidence where enhanced improvement in longevity and increasing multimorbidity have similar effects on men and women, plugging earlier gaps in use of care and results [21].

There were significant racial and ethnic disparities during the study duration. Non-Hispanic Black adults in all regions consistently reported higher glaucoma mortality compared to Whites and Hispanics. This is consistent with much of decades of epidemiologic evidence for a more rapid onset, faster rate of progression, and greater glaucoma severity in Blacks [22, 23]. Biologic susceptibility in the form of thinner corneal thickness and increased burden of more advanced open-angle glaucoma subtypes is augmented by social determinants such as decreased access to subspecialty services, decreased rates of surgical follow-up, and system-level healthcare inequities in infrastructure [24]. The rising mortality trend for Black adults is concerning and in line with evidence that specialist disparities in the availability of healthcare have increased since 2015 [25]. Hispanic adults, on the other hand, had lower mortality as seen in prevalence studies earlier, although rising diabetes and hypertension burden within the cohort perhaps to redirect future trends [26]. All these differences prove that global, behavioral, and biological determinants converge to create a mortality gradient by race. The most dramatic gradient was

demonstrated in age-stratified analysis and is described in older persons with the highest burden of mortality associated with glaucoma.

All global cohort studies identify increasing age as the most significant disease course and risk factor for visual impairment. Late-life survival gains once depended on successful surgery, new classes of drugs, and increasing Medicare-sponsored screening of the eyes. The resulting increase is nonetheless in line with the demographic increase of the oldest-old population and increasing frailty, multimorbidity, and polypharmacy to exert risk [27, 28]. Adults aged 65–74 years evidenced more gradual and slower rising rates, as would be predicted by the hypothesis that disease states at earlier stages in the course of the disease are best treated by longer duration therapy and fewer systemic comorbidities [29]. The age disparity serves to highlight the fact that glaucoma mortality is no less an index of systemic susceptibility than of ocular disease. Urbanizing trends were imposed upon rural disadvantage.

Non-metropolitan residents have always had higher glaucoma mortality compared with metropolitan residents. These results are consistent with those of rural ophthalmologist shortages, greater travel distances to special care services, and greater continuity-of-care issues. Rural-urban disparities during previous years presumably resulted from national expansions of Medicare coverage and eye care utilization [30, 31]. Yet rural disadvantage remerges more recently with clinic closures, transportation issues, and reduced availability of subspecialists. Urban populations also evidenced lagging growth, that is, even the wealthiest environments are not exempt from the cumulative effects of aging and systemic disease [32]. Geographic variation also evidenced convergence of trends in demographics and health system capacity.

The Midwest experienced record-high rates but achieved long-term decreases, and these most likely resulted from an initial high burden combined with judicious utilization of surgical and community-based eye care programs. Northeast experienced unstable trends, which is typical of its very heterogeneous population and mixed health infrastructure. South had lower mean rates but with a high total number of deaths, in accordance with its race and size, and long-standing differences in provision. West fluctuated up and down until late on, in accordance with demographic change, rising migration, and skewed distribution of healthcare facilities. These trends emphasize the necessity for region-level interventions that take into consideration both sociodemographic conditions and health system capability [33, 34]. Death trends of nursing homes contributed additional information about populations most impacted.

The prevalence of glaucoma death among nursing homes and long-term care facilities highlights the susceptibility of frail, dependent elderly persons. Such groups are at higher risk for severe comorbidity and lower accessibility to specialty ophthalmologic treatment, raising the risk of death. Hospital mortality relative to other chronic illnesses is consistent with the literature describing glaucoma as more disabling and causative than acute terminal in nature [35, 36]. Home death frequency is consistent with end-of-life care unmet needs and visually impaired older person support, described consistently throughout geriatric care literature as being a chronic shortcoming.

4.1 Limitations

Dependence on death certificate data has the potential for misclassification of risk because glaucoma is an uncommon main cause of death, but instead often occurs episodically as a contributing cause. Inter-state and inter-temporal variation in rules for certification and coding may alter observed mortality patterns. Second, small numbers culling in CDC WONDER limited the capacity to estimate less prevalent racial and geographic subgroups reasonably, which may suppress inequities. Third, ecological design will not allow adjustment for variables at the individual level, such as socioeconomic status, treatment adherence, or disease comorbid burden, all of which have been shown to affect outcomes. Fourth, changes in diagnostic methods, improvement in treatment, and usage of healthcare during the observation interval cannot be completely divorced from underlying trends in epidemiology. Beyond such limitations, the article presents a broad nationwide image of long-term demographic and geographical trends in glaucoma fatalities.

5.0 CONCLUSION

Taken together, these data place glaucoma not just as an ocular disease, but as an expression of systemic susceptibility and imbalance. This pattern of escalating early losses with subsequent gains both reflects poor people's victory over disease and the limitation of poor people's asymmetric access and population pressure. Stratified sex, race, age, urbanization, and geographic estimates affirm glaucoma mortality burden remains disproportionately skewed, based on a sophisticated interplay of biological risk, health system, and structural disadvantage.

Abbreviations

AAMR
Age–adjusted Mortality Rate
CMR
Crude Mortality Rate
AAPC
Average Annual Percent Change
APC
Annual Percent Change
CDC WONDER
Centers for Disease Control and Prevention Wide–Ranging Online Data for Epidemiologic Research
ICD
10–International Statistical Classification of Disease and Related Health Problems, 10th Revision
NH
non–Hispanic
U.S
United States

UCD
Underlying Cause of Death

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Data availability

The datasets generated and/or analysed during the current study are publicly available, de-identified data from the CDC WONDER Multiple Cause-of-Death database. Available at: https://wonder.cdc.gov/mcd.html

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

MA: conceptualization, project administration, supervision, validation, investigation, methodology, writing, writing – original draft, writing – review and editing; NHK: investigation, methodology, writing – original draft, writing – review and editing; AK: investigation, methodology, writing – original draft, writing – review and editing; SUR: investigation, methodology, writing – original draft, writing – review and editing; NZ: investigation, methodology, writing – original draft, writing – review and editing; RF: investigation, methodology, writing – original draft; MSA: graph and figure curation; MM: figure curation; IA: investigation, methodology, writing – original draft, writing – review and editing; AR: methodology– original draft, writing – review and editing; KAK: writing – review and editing; HS: writing – review and editing; MAS: writing – review and editing. All authors read and approved the final manuscript.

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Fig. 7 and Fig. 8 were created using Datawrapper. Available at: https://www.datawrapper.de/

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Figures

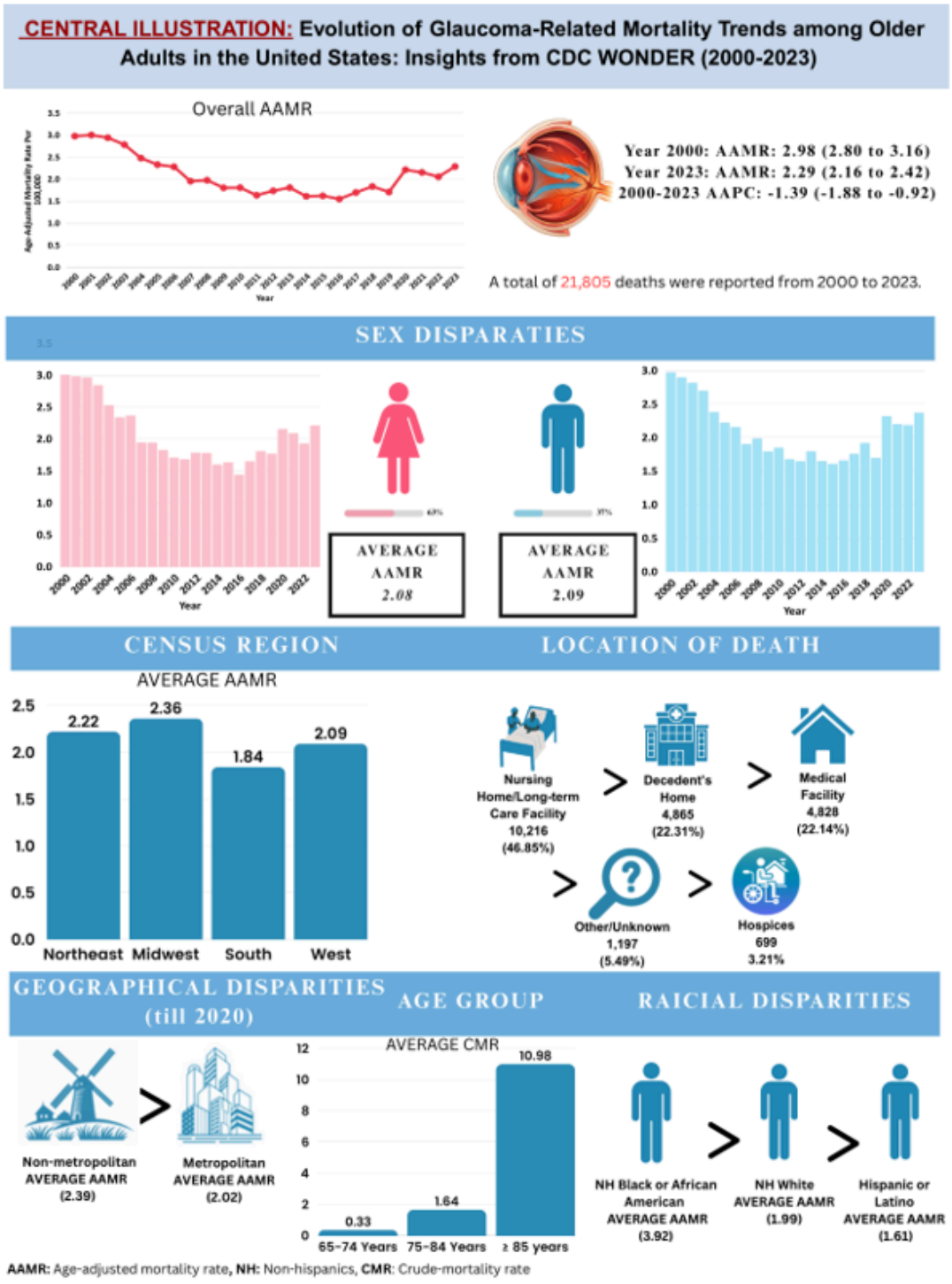


Figure 1

Central Illustration.

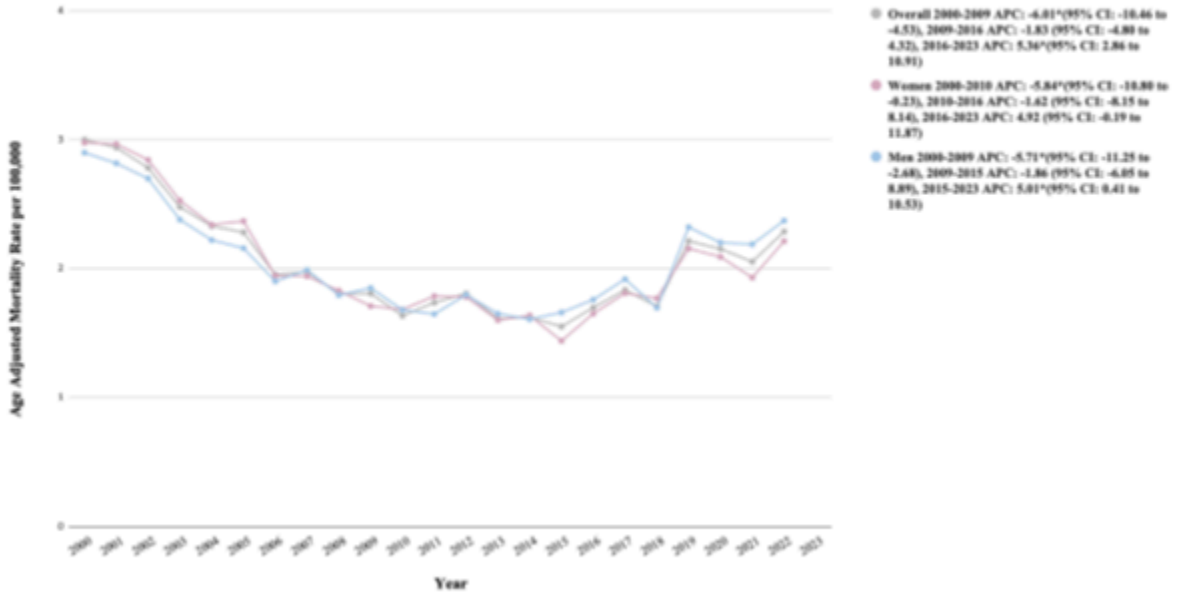


Figure 2

Trends in Glaucoma-Related Age-Adjusted Mortality Rate by Sex, 2000 to 2023.

*Indicates APC is significantly different from 0

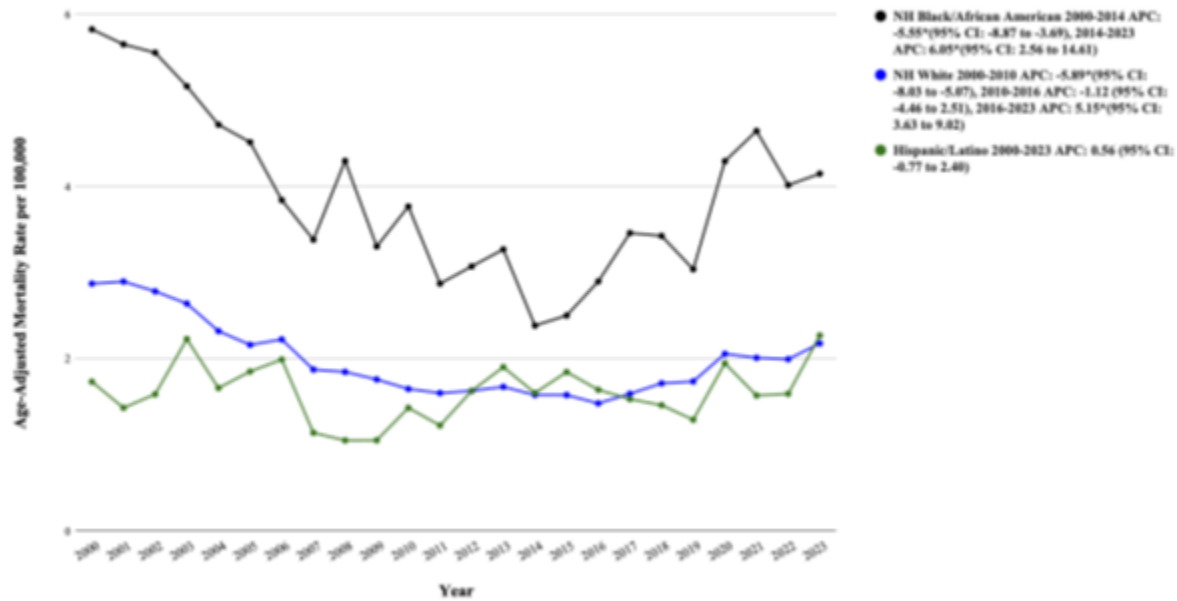


Figure 3

Trends in Glaucoma-Related Age-Adjusted Mortality Rate by Race, 2000 to 2023.

NH = non-Hispanic

*Indicates APC is significantly different from 0

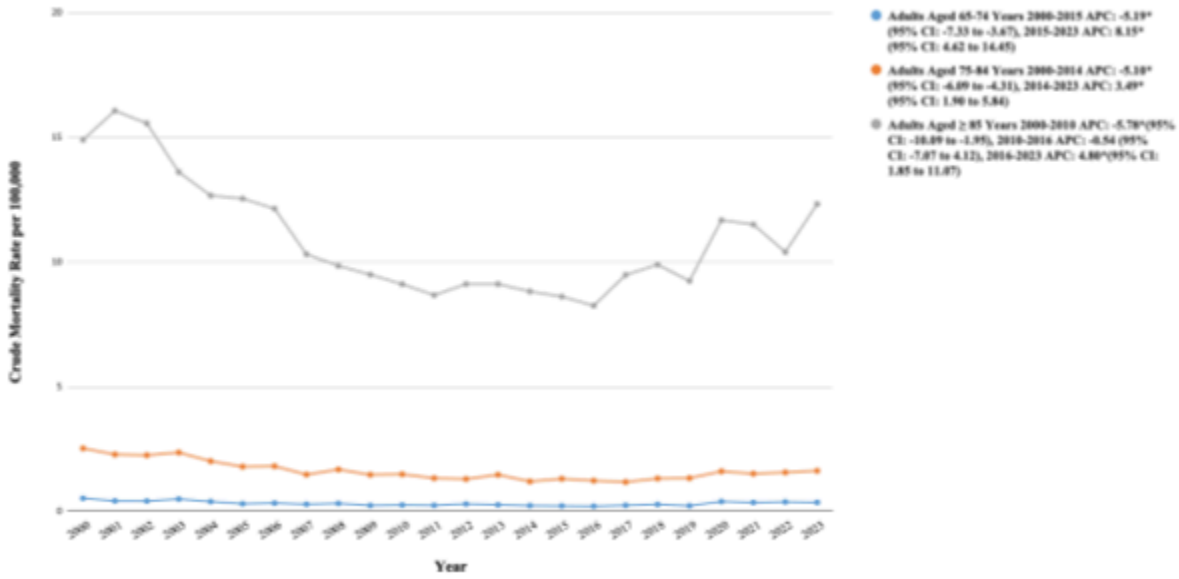


Figure 4

Trends in Glaucoma-Related Crude Mortality Rate by Age Group, 2000 to 2023.

*Indicates APC is significantly different from 0

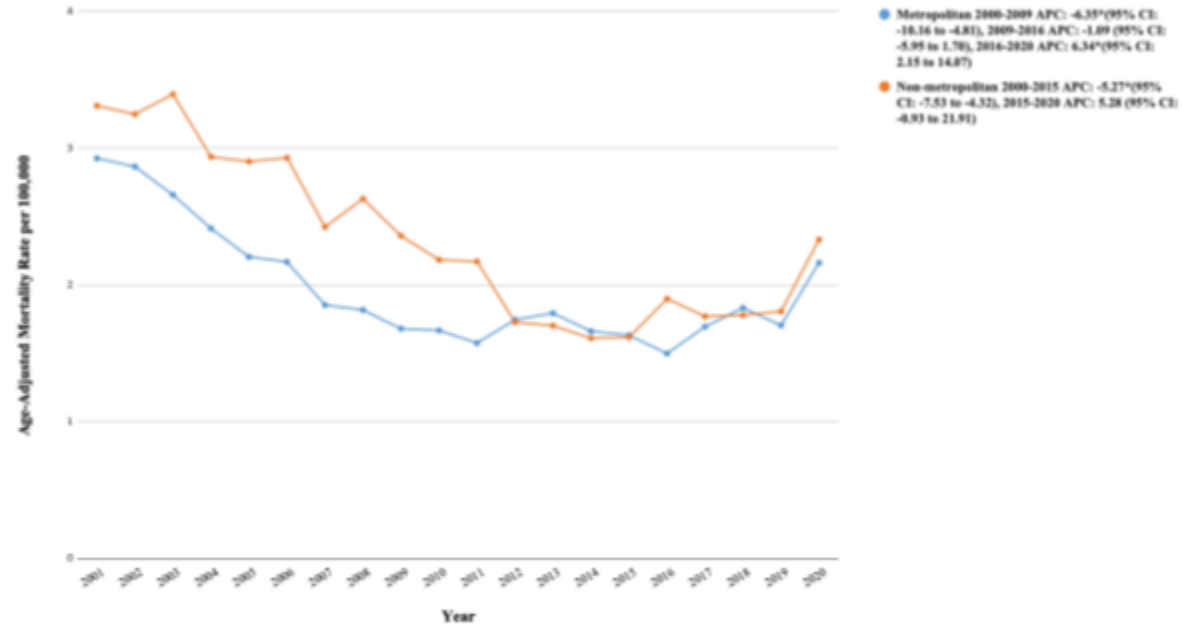


Figure 5

Trends in Glaucoma-Related Age-Adjusted Mortality Rate by Urbanization, 2000 to 2020.

*Indicates APC is significantly different from 0

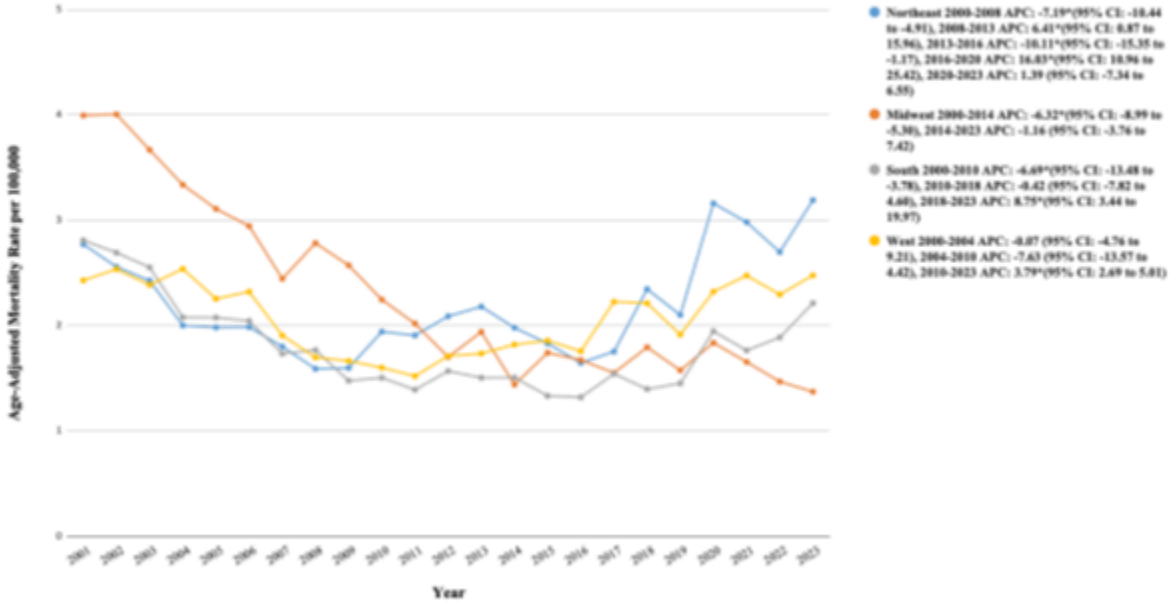


Figure 6

Trends in Glaucoma-Related Age-Adjusted Mortality Rate by Census Region, 2000 to 2023.

*Indicates APC is significantly different from 0

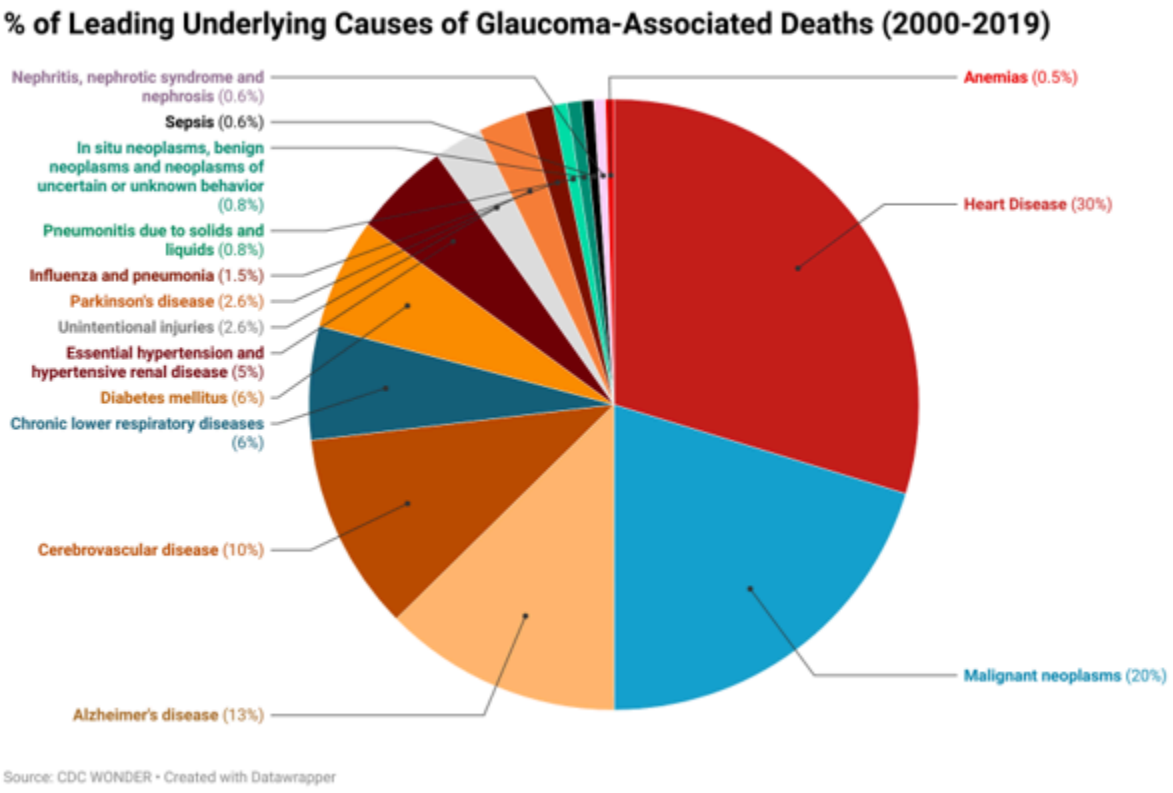


Figure 7

Leading Underlying Causes of Glaucoma-Associated Death by % of Deaths, 2000 to 2019.

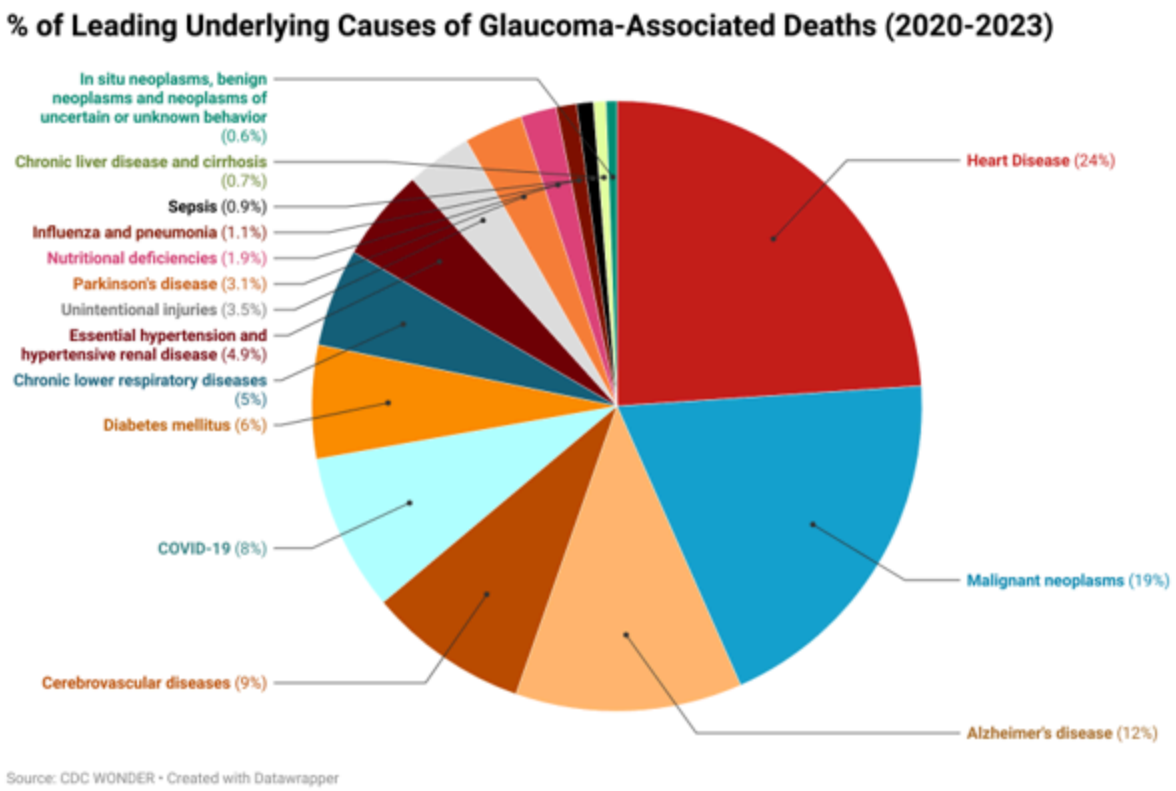


Figure 8

Leading Underlying Causes of Glaucoma-Associated Death by % of Deaths, 2020 to 2023.

Supplementary Files

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- SupplementaryFile1.docx