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A national stratification of the global macroeconomic burden of central nervous system cancer

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OBJECTIVE Country-by-country estimates of the macroeconomic disease burden of central nervous system (CNS) cancers are important when determining the allocation of resources related to neuro-oncology. Accordingly, in this study the authors investigated macroeconomic losses related to CNS cancer in 173 countries and identified pertinent epidemiological trends.

METHODS Data for CNS cancer incidence, mortality, and disability-adjusted life years (DALYs) were collected from the Global Burden of Disease 2019 database. Gross domestic product data were combined with DALY data to estimate economic losses using a value of lost welfare approach.

RESULTS The mortality-to-incidence ratio of CNS cancer in 2019 was 0.60 in high-income regions compared to 0.82 in Sub-Saharan Africa and 0.87 in Central Europe, Eastern Europe, and Central Asia. Welfare losses varied across both high- and low-income countries. Welfare losses attributable to CNS cancer in Japan represented 0.07% of the gross domestic product compared to 0.23% in Germany. In low- and middle-income countries, Iraq reported welfare losses of 0.20% compared to 0.04% in Angola. Globally, the DALY rate in 2019 was the same for CNS cancer as for prostate cancer at 112 per 100,000 person-years, despite a 75% lower incidence rate, equating to CNS cancer welfare losses of 182 billion US dollars.

CONCLUSIONS Macroeconomic losses vary across high- and low-income settings and appear to be region specific. These differences may be explained by differences in regional access to screening and diagnosis, population-level genetic predispositions, and environmental risk factors. Mortality-to-incidence ratios are higher in low- and middle-income countries than in high-income countries, highlighting possible gaps in treatment access. Quantification of macroeconomic losses related to CNS cancer can help to justify the spending of finite resources to improve outcomes for neuro-oncological patients globally.

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KEYWORDS central nervous system cancers; macroeconomic burden; value of lost welfare; disability-adjusted life years; oncology

P RIMARY central nervous system (CNS) cancers had a global incidence of 330,000 and overall mortality of 230,000 in 2016;¹ these data represent an increase in incidence of 20% since 1990. Disease burden related to CNS cancer is disproportional to the overall incidence,

given the very high morbidity and mortality associated with these cancers.^{2,3} In low-resource settings such as in many low- and middle-income countries (LMICs), this discrepancy is further amplified given the complexity of CNS cancer management, which typically involves a mul-

ABBREVIATIONS CNS = central nervous system; DALY = disability-adjusted life year; GDP = gross domestic product; IE = income elasticity; LMICs = low- and middle-income countries; PPP = purchasing power parity; USD = US dollar; VLW = value of lost welfare; VSL = value of statistical life.

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tidisciplinary approach centered on neurosurgery, chemotherapy, and radiation.^{4,5}

A firm understanding of both epidemiological and economic trends in CNS cancer is important for effective resource allocation on both national and international levels.^{6,7} Understanding these trends includes identifying areas with poor access to diagnostic modalities and treatment and also requires the contextualization of CNS cancer costs in relation to those for other oncological disease.⁸ Although macroeconomic cost analyses of both surgical and neurosurgical diseases in specific regions have been conducted,^{9–11} to our knowledge no previous study has attempted to assess the global economic losses associated with CNS cancer on a country-by-country basis. Given that the absence of such economic data has been shown to deter both prioritization of health policies and attention to global health issues,¹² it is our contention that such work may ultimately help stakeholders justify resource allocation and in so doing improve patient care globally.

The value of lost welfare (VLW) model can be used to calculate economic losses in a standardized manner and incorporates both disability-adjusted life years (DALYs) and the concept of the value of statistical life (VSL), which is defined as the value an individual is willing to pay to decrease the risk of mortality.¹³ By incorporating VSL, the VLW method allows for the overall assessment of economic welfare losses, including nonmarket goods and services, and the value of health itself.¹³ In contrast, the extensively used cost-of-illness approaches generally fail to consider unemployment, depleted capital accumulation, investment in human capital, and demographic changes in relation to economic growth, and have therefore been discouraged by the World Health Organization.^{14,15}

The primary aim of this study was to estimate macroeconomic losses attributable to CNS cancer in 2000 and 2019 in 173 countries from high-, middle-, and low-income environments. Secondary aims included contextualizing the calculated economic burden both into economic losses due to CNS cancer compared to those from other oncological diseases and into published trends of CNS cancer incidence, mortality, and DALYs globally according to the Global Burden of Disease study superregion.⁸

Methods

Data Sources, Variables, and Population

Using the Institute of Health Metrics and Evaluation database, we obtained the Global Burden of Disease study data related to primary CNS cancers for the years 2000–2019.⁸ Metastatic and benign tumors are not considered in the Global Burden of Disease study and therefore were not included in the economic analysis conducted in this study. Primary CNS cancer, as defined by the Global Burden of Disease study, includes ICD-10 codes C70.0–C72.9 (C70 = malignant neoplasm of the meninges; C71 = malignant neoplasm of the brain, malignant neoplasm of the spinal cord, cranial nerves, and other parts of the CNS). A description of all ICD codes included can be found in Supplemental Table 1. Given that ICD-10 codes are based on cancer site rather than histology, the Global Burden of Disease data set does not include data for different CNS

cancer subtypes. An economic analysis of CNS cancer subtypes was therefore not possible.

Data were collected from 173 countries and included incidence, mortality, and DALYs per year per 100,000 people.⁸ The DALY, a measure of total burden of disease, is the sum of years of life lost, which measures premature mortality and years lost due to disability; as such, this measure accounts for the extent of morbidity experienced due to disability.¹⁶ The World Development Indicator Database, provided by the World Bank, was used to gather economic data in the form of gross domestic product (GDP) and GDP per capita, with purchasing power parity (PPP) adjustment to the 2017 US dollar (USD).¹⁷ Global Burden of Disease study superregions were used to group countries.⁸ There are seven Global Burden of Disease study superregions: 1) Central Europe, Eastern Europe, Central Asia; 2) High Income; 3) Latin America, Caribbean; 4) North Africa, Middle East; 5) South Asia; 6) Southeast Asia, East Asia, Oceania; and 7) Sub-Saharan Africa.⁸

Calculation of Value of Lost Welfare

The VLW approach has been increasingly used in cost analyses of macroeconomic disease burden.^{9–11,18} The VSL, as defined briefly above, represents the maximum dollar value an individual is willing to pay to prevent death. Combined with the DALYs of a particular disease, VSL can be used to calculate the total macroeconomic burden of disease. VSL must be determined empirically, and this determination has been done only in a few mostly high-income countries. Therefore, to estimate VSL for all countries, the following formula was employed, which makes inferences based on known data derived from the US:^{9,18} $VSL_{peak,i} = VSL_{peak,USA} (GDP_i^{IE}/GDP_{USA})$, where i is the GDP per capita of country i and IE is income elasticity.

With this formula, the GDP per capita of a specific country can be adjusted to that of the US after PPP adjustment. Further adjustment for willingness to pay can be done via the employment of the IE parameter. The gold-standard IE when converting between high-income regions has been 0.55; however, more conservative IE s of 1.0 and 1.5 have been used when converting from high- to low-income settings.^{9,13,18} For the purposes of this study, an IE of 1.0 was selected in an effort to minimize assumptions about willingness to pay after adjustment for GDP per capita and purchasing power. However, supplemental country-by-country analyses using IE s of 0.55 and 1.5 were conducted to account for stakeholders making local willingness-to-pay assumptions after income adjustment. Moreover, VSL is known to vary depending on age, a factor for which further adjustment was conducted. The VSL_{peak} represents the age at which individuals in an economy are willing to pay the most to prevent death. The peak is not at the end of life, when decreases in risk bring the least utility, nor is it at the beginning of life. VSL has rather been shown to follow an inverted U-shaped distribution, with VSL_{peak} being around middle age.¹³ To estimate VSL for any individual year (VSLY), VSL_{peak} was adjusted using a function known as $f(a)$, and VSLY was subsequently multiplied by DALYs incurred that year.¹³ The resulting product makes up the total VLW in USD.

TABLE 1. Trends in incidence (cases per year per 100,000 people), mortality (deaths per year per 100,000 people), mortality-to-incidence ratio, and DALY (per year per 100,000 people) by Global Burden of Disease study superregion

GBD Superregion	2000				2019				Change From 2000 to 2019 (%)			
	I	M	M/I	DALY	I	M	M/I	DALY	I	M	M/I	DALY
Central Europe, Eastern Europe, & Central Asia	5.48	4.80	0.88	180	6.71	5.87	0.87	197	22.58	22.45	-0.11	9.80
High Income	7.53	4.89	0.65	151	9.60	5.80	0.60	160	27.41	18.58	-6.94	6.31
Latin America & Caribbean	3.12	2.52	0.81	111	4.06	3.32	0.82	122	29.99	31.59	1.23	9.53
North Africa & Middle East	3.14	2.30	0.73	110	4.52	2.92	0.65	118	43.97	26.78	-11.94	7.21
South Asia	1.90	1.57	0.82	84	2.06	1.70	0.83	77	8.43	8.70	0.25	-8.89
Southeast Asia, East Asia, & Oceania	3.73	2.99	0.80	128	5.26	3.68	0.70	124	41.04	23.05	-12.76	-3.55
Sub-Saharan Africa	1.17	0.95	0.81	54	1.29	1.06	0.82	57	9.84	10.94	1.00	4.94

GBD = Global Burden of Disease; I = incidence; M = mortality; M/I = mortality-to-incidence ratio.

The VLW approach thus considers the life lost in the given year combined with the present value of future life lost, at a discounted rate. All calculations were conducted using RStudio IDE (RStudio, PBC).

Ethics Statement

This study used publicly available de-identified data aggregated at a country level, and thus was considered exempt as nonhuman subjects research by our institutional review board.

Results

Global Trends

In 2019 there were 348,000 cases of CNS cancer and 246,000 related mortalities, representing a global burden of 8.7 million DALYs, which translated into welfare losses of 182 billion USD or 0.15% of GDP for the 173 countries included in the study. Between the years 2000 and 2019, there was a 21.7% increase in incidence (cases per 100,000 people: 3.70 in 2000, increased to 4.50 in 2019), a 13.4% increase in mortality (mortalities per 100,000 people: 2.81 in 2000, increased to 3.18 in 2019), and a 3.2% decrease in DALYs (DALYs per 100,000 people: 115.41 in 2000, decreased to 111.92 in 2019). Incidence and mortality rates increased in all seven Global Burden of Disease study superregions examined.

Mortality and Incidence

In 2019, the superregions with the highest incidence were the High Income superregion (9.60 cases per 100,000 people) and the Central Europe, Eastern Europe, and Central Asia superregion (6.71 cases per 100,000 people), compared to the superregions with the lowest incidence, South Asia (2.06 cases per 100,000 people) and Sub-Saharan Africa (1.29 cases per 100,000 people). Incidence increased in all Global Burden of Disease study superregions between the years 2000 and 2019. The highest rates of mortality in 2019 were also reported in the High Income and Central Europe, Eastern Europe, and Central Asia superregions at 5.80 and 5.87 mortalities per 100,000 people, respectively. Moreover, the superregions with the lowest mortality rates in 2019 were South Asia (1.70 cases

per 100,000 people) and Sub-Saharan Africa (1.06 cases per 100,000 people). All seven Global Burden of Disease study superregions reported an increase in mortality between the years 2000 and 2019. Mortality-to-incidence ratios in 2019 were highest in the Sub-Saharan Africa and Central Europe, Eastern Europe, and Central Asia superregions (0.82 and 0.87, respectively) compared to 0.60 in the High Income superregion (Table 1).

Burden of Disease and Resulting Welfare Loss

Globally in 2019, the Central Europe, Eastern Europe, and Central Asia and High Income superregions had the highest DALY rates at 197 and 160, respectively, which translated into welfare losses of 19.55 billion USD in the Central Europe, Eastern Europe, and Central Asia superregion and 90.60 billion USD in the High Income superregion, representing 0.21% and 0.17% of the superregional GDPs, respectively. The superregions with the lowest DALY rates in 2019 were South Asia and Sub-Saharan Africa, with 77 and 57 DALYs per 100,000 people, respectively. This translated into welfare losses of 7.78 billion USD in South Asia and 1.80 billion USD in Sub-Saharan Africa, representing welfare losses of 0.07% and 0.05% of the GDPs, respectively (Table 2).

Disease burden and resulting welfare losses varied across both high- and low-income countries. In high-income settings, countries such as Japan and Singapore displayed relatively low welfare losses at 0.07% and 0.06% of their GDPs, respectively, in contrast to Germany and Italy, which had estimated welfare losses of 0.23% and 0.19% of their GDPs, respectively. Moreover, differences were also noted in LMICs; Iraq reported welfare losses of 0.20% compared to 0.04% in Angola. Such geographic distributions and findings are further illustrated in Table 3 and Fig. 1.

Regarding oncological disease categories as defined by the Global Burden of Disease study, CNS cancer had the 11th highest welfare losses at 182 billion USD, and these losses were comparable to losses associated with prostate cancer at 184 billion USD (Fig. 2). The supplemental country-by-country analysis of CNS cancer VLW using IEs of 0.55 and 1.5 is presented in Supplemental Tables 2 and 3, respectively.

TABLE 2. VLW due to CNS cancer in USD (2017, PPP) and as a share of GDP in 2000 and 2019 by Global Burden of Disease study superregion

GBD Superregion	2000		2019	
	VLW (billion USD)	VLW/GDP (%)	VLW (billion USD)	VLW/GDP (%)
Central Europe, Eastern Europe, & Central Asia	19.55	0.21	11.50	0.24
High Income	90.60	0.17	78.64	0.21
Southeast Asia, East Asia, & Oceania	40.78	0.13	10.99	0.15
North Africa & Middle East	11.63	0.12	5.65	0.12
Latin America & Caribbean	9.94	0.12	6.47	0.13
South Asia	7.78	0.07	2.88	0.08
Sub-Saharan Africa	1.80	0.05	0.83	0.05

Discussion

This study highlights trends in incidence, mortality, DALYs, and resulting welfare losses globally between 2000 and 2019 for cancers of the CNS. During this period, both the global incidence and mortality associated with CNS cancers were shown to increase, highlighting the need to further assess the associated economic burden and allocation of both clinical and research resources.

The economic data presented in the present study can be used to help justify efforts to improve access to neuro-oncological care where it is the most needed. A crude proxy for treatment access is the mortality-to-incidence ratio, which was the lowest in the High Income Global Burden of Disease study superregion.¹⁹ Given the extreme mortality of CNS cancer even in high-income settings, differences in the mortality-to-incidence ratio were not as pronounced as in other diseases indexed within the Global Burden of Disease study.²⁰ Nevertheless, in other reports CNS cancer mortality-to-incidence ratios have been shown to decrease as the social development index in a region improves.¹ Lack of access to neuro-oncological diagnostics and care has been well documented across a litany of LMICs, with 34 countries, all LMICs, having been shown to lack neurosurgeons as of 2019.^{21–25} The continued funding and development of neuro-oncological human resources in LMICs is essential in addressing disparities that presently exist;⁵ to do so, wide-ranging cancer registries and improved systematic data collection are needed.²⁶ Presently, broad economic data to justify such interventions are scarce in LMICs,²⁷ and to the authors' knowledge, this study is the first attempt to provide such data on a country-by-country basis for cancers of the CNS.¹²

Although treatment is less accessible in LMICs, the distribution of CNS cancer welfare losses seems in part to be dependent on geographic location rather than income level alone. There are several potential contributors to such a pattern, including population-level genetic predisposition, regional access to screening and diagnosis, and potential environmental risk factors. In terms of genetic predisposition, Germany and Japan, for example, have comparable GDPs per capita and social development indices,¹⁷ yet welfare losses as a share of GDP in Japan were less than one-third of those in Germany. Population-based regis-

try studies from the US have shown similar differences between corresponding US ethnic groups, with the incidence of CNS cancer among Asians being less than half that of non-Hispanic Whites.^{28–30} Racial and ethnic differences may similarly explain differences between LMIC regions, with countries such as Iraq reporting markedly higher welfare losses as a share of GDP than, for example, Angola, despite a comparable GDP per capita.¹⁷ These differences were again concordant with incidence in the corresponding ethnic groups in US registry-based studies.^{28–30} Genetic predisposition may therefore potentially account for a proportion of differences noted in regional disease burdens.

Another reason for regional differences in welfare losses is differences in access to screening and diagnosis.^{31,32} The healthcare access and quality index developed by the Global Burden of Disease study identified Sub-Saharan African countries as those with the poorest access to healthcare.³³ The absence of advanced imaging modalities in addition to radiologists, neurologists, oncologists, and neurosurgeons presents a clear problem with regard to the diagnostic accuracy and epidemiological data used in the present economic model.¹ In terms of geographic distribution of welfare losses, it is also prudent to note that environmental risk factors, such as radiation and chemical exposure, are unevenly distributed across regions.^{1,34} Finally, although there was a global increase noted in both incidence and mortality in our study, a substantial proportion of this increase is likely due to improved dissemination of diagnostic capabilities and changes in reporting practices of CNS cancer registries.^{35,36}

Investment in clinical trials has been correlated with subsequent decreases in oncological disease burden in a study considering non-small cell lung cancer and melanoma, thyroid, prostate, colon, and breast cancers.³⁷ Although it is hard to prove whether such investments are actually causal, the CNS cancer cost analysis herein presented gives stakeholders an estimate of the magnitude of welfare losses that can be decreased when planning resource allocation. For example, in relation to other oncological disease, global welfare losses related to CNS cancer were comparable to those of prostate cancer; this finding is remarkable given that the incidence of CNS cancer is 75% lower than that of prostate cancer.¹ Despite

TABLE 3. VLW due to CNS cancer in USD (2017, PPP) and as a share of the GDP in 2000 and 2019 for 176 countries

Country	2000		2019	
	VLW (billion USD)	VLW/ GDP (%)	VLW (billion USD)	VLW/ GDP (%)
Afghanistan	—	—	0.10	0.12
Albania	0.05	0.25	0.10	0.25
Algeria	0.17	0.06	0.27	0.05
Angola	0.04	0.05	0.09	0.04
Antigua & Barbuda	0.00	0.07	0.00	0.08
Argentina	0.93	0.14	1.24	0.13
Armenia	0.04	0.29	0.10	0.25
Australia	1.79	0.24	2.41	0.19
Austria	0.86	0.23	0.94	0.19
Azerbaijan	0.07	0.21	0.29	0.20
Bahamas	0.01	0.09	0.01	0.09
Bahrain	0.03	0.08	0.05	0.07
Bangladesh	0.20	0.08	0.46	0.06
Barbados	0.00	0.09	0.01	0.11
Belarus	0.15	0.19	0.32	0.17
Belgium	1.13	0.26	1.20	0.20
Belize	0.00	0.06	0.00	0.07
Benin	0.01	0.04	0.02	0.05
Bermuda	0.01	0.13	0.01	0.14
Bhutan	0.00	0.10	0.01	0.07
Bolivia (Plurinational State of)	0.05	0.10	0.11	0.11
Bosnia & Herzegovina	0.08	0.31	0.16	0.32
Botswana	0.01	0.06	0.03	0.07
Brazil	3.68	0.18	5.53	0.18
Brunei Darussalam	0.03	0.13	0.04	0.14
Bulgaria	0.21	0.25	0.52	0.32
Burkina Faso	0.01	0.04	0.02	0.06
Burundi	0.00	0.05	0.00	0.05
Cabo Verde	0.00	0.11	0.00	0.10
Cambodia	0.02	0.09	0.07	0.09
Cameroon	0.02	0.04	0.05	0.05
Canada	2.47	0.22	3.49	0.19
Central African Republic	0.00	0.05	0.00	0.05
Chad	0.00	0.04	0.01	0.04
Chile	0.21	0.09	0.45	0.09
China	8.13	0.19	34.24	0.15
Colombia	0.42	0.12	0.72	0.10
Comoros	0.00	0.04	0.00	0.04
Congo	0.01	0.05	0.01	0.04
Costa Rica	0.05	0.10	0.10	0.10
Croatia	0.28	0.34	0.36	0.31
Cyprus	0.05	0.21	0.08	0.23
Czechia	0.74	0.29	0.95	0.22
Democratic Republic of the Congo	0.02	0.04	0.03	0.04

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TABLE 3. VLW due to CNS cancer in USD (2017, PPP) and as a share of the GDP in 2000 and 2019 for 176 countries

Country	2000		2019	
	VLW (billion USD)	VLW/ GDP (%)	VLW (billion USD)	VLW/ GDP (%)
Denmark	0.87	0.33	0.83	0.25
Djibouti	—	—	0.00	0.06
Dominican Republic	0.03	0.04	0.06	0.03
Ecuador	0.08	0.08	0.20	0.10
Egypt	0.52	0.10	1.01	0.09
El Salvador	0.04	0.10	0.06	0.10
Equatorial Guinea	0.00	0.05	0.01	0.04
Estonia	0.07	0.27	0.10	0.21
Eswatini	0.00	0.05	0.01	0.05
Ethiopia	0.03	0.07	0.11	0.04
Fiji	0.01	0.07	0.01	0.06
Finland	0.57	0.28	0.55	0.20
France	5.13	0.21	5.69	0.18
Gabon	0.01	0.05	0.01	0.04
Gambia	0.00	0.02	0.00	0.02
Georgia	0.04	0.18	0.13	0.23
Germany	10.27	0.29	10.10	0.23
Ghana	0.06	0.11	0.17	0.10
Greece	1.20	0.38	1.00	0.31
Grenada	0.00	0.07	0.00	0.09
Guatemala	0.06	0.07	0.10	0.07
Guinea	0.00	0.03	0.01	0.03
Guinea-Bissau	0.00	0.05	0.00	0.05
Guyana	0.00	0.05	0.00	0.05
Haiti	0.02	0.08	0.03	0.09
Honduras	0.02	0.08	0.04	0.06
Hungary	0.58	0.29	0.64	0.20
Iceland	0.04	0.31	0.05	0.24
India	2.20	0.08	6.36	0.07
Indonesia	1.04	0.09	2.35	0.07
Iran (Islamic Republic of)	0.99	0.15	1.66	0.16
Iraq	0.44	0.20	0.84	0.20
Ireland	0.44	0.24	0.85	0.20
Israel	0.44	0.22	0.66	0.18
Italy	5.52	0.23	4.96	0.19
Jamaica	0.01	0.06	0.02	0.05
Japan	2.91	0.06	3.80	0.07
Jordan	0.04	0.09	0.09	0.09
Kazakhstan	0.11	0.07	0.59	0.12
Kenya	0.04	0.04	0.10	0.05
Kiribati	0.00	0.05	0.00	0.04
Kuwait	0.07	0.06	0.13	0.06
Kyrgyzstan	0.01	0.09	0.03	0.09

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TABLE 3. VLW due to CNS cancer in USD (2017, PPP) and as a share of the GDP in 2000 and 2019 for 176 countries

Country	2000		2019	
	VLW (billion USD)	VLW/ GDP (%)	VLW (billion USD)	VLW/ GDP (%)
Lao (People's Democratic Republic)	0.02	0.10	0.05	0.08
Latvia	0.08	0.26	0.14	0.23
Lebanon	0.07	0.13	0.09	0.09
Lesotho	0.00	0.04	0.00	0.05
Liberia	0.00	0.04	0.00	0.04
Libya	0.11	0.12	0.14	0.14
Lithuania	0.12	0.25	0.24	0.23
Luxembourg	0.14	0.33	0.17	0.24
Madagascar	0.01	0.04	0.02	0.04
Malawi	0.00	0.05	0.01	0.04
Malaysia	0.27	0.07	0.62	0.07
Maldives	0.00	0.08	0.01	0.07
Mali	0.00	0.02	0.01	0.03
Malta	0.02	0.21	0.04	0.16
Marshall Islands	0.00	0.08	—	—
Mauritania	0.00	0.03	0.01	0.03
Mauritius	0.01	0.08	0.02	0.07
Mexico	1.54	0.09	2.04	0.08
Micronesia (Federated States of)	0.00	0.08	0.00	0.07
Moldova (Republic of)	0.04	0.25	0.08	0.23
Mongolia	0.01	0.09	0.05	0.13
Montenegro	0.03	0.42	0.04	0.33
Morocco	0.07	0.06	0.15	0.05
Mozambique	0.01	0.06	0.02	0.05
Myanmar	0.06	0.11	0.24	0.09
Namibia	0.01	0.05	0.01	0.05
Nepal	0.03	0.07	0.06	0.06
Netherlands	1.69	0.22	1.87	0.19
New Zealand	0.29	0.23	0.36	0.17
Nicaragua	0.01	0.06	0.02	0.07
Niger	0.00	0.04	0.01	0.04
Nigeria	0.19	0.05	0.49	0.05
North Macedonia	0.07	0.35	0.11	0.31
Norway	0.75	0.29	0.79	0.23
Oman	0.05	0.06	0.07	0.05
Pakistan	0.45	0.10	0.88	0.09
Palau	0.00	0.09	—	—
Panama	0.04	0.10	0.13	0.10
Papua New Guinea	0.01	0.06	0.03	0.07
Paraguay	0.03	0.07	0.06	0.06
Peru	0.23	0.14	0.54	0.13
Philippines	0.31	0.09	0.76	0.08

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TABLE 3. VLW due to CNS cancer in USD (2017, PPP) and as a share of the GDP in 2000 and 2019 for 176 countries

Country	2000		2019	
	VLW (billion USD)	VLW/ GDP (%)	VLW (billion USD)	VLW/ GDP (%)
Poland	1.94	0.31	3.29	0.26
Portugal	0.81	0.26	0.86	0.24
Puerto Rico	0.10	0.09	0.11	0.10
Qatar	0.05	0.10	0.18	0.07
Romania	0.68	0.25	1.41	0.24
Russian Federation	4.52	0.21	6.93	0.17
Rwanda	0.00	0.05	0.01	0.05
Saint Lucia	0.00	0.06	0.00	0.07
Saint Vincent & the Grenadines	0.00	0.07	0.00	0.08
Samoa	0.00	0.06	0.00	0.06
São Tomé & Príncipe	—	—	0.00	0.01
Saudi Arabia	0.65	0.08	1.51	0.09
Senegal	0.01	0.03	0.02	0.04
Serbia	0.30	0.46	0.47	0.37
Seychelles	0.00	0.17	0.00	0.18
Sierra Leone	0.00	0.05	0.01	0.05
Singapore	0.14	0.06	0.36	0.06
Slovakia	0.20	0.24	0.37	0.21
Slovenia	0.13	0.24	0.16	0.19
Solomon Islands	0.00	0.10	0.00	0.08
South Africa	0.28	0.06	0.41	0.06
Spain	3.13	0.22	3.76	0.20
Sri Lanka	0.08	0.07	0.23	0.08
Sudan	0.06	0.09	0.17	0.09
Suriname	0.01	0.10	0.01	0.13
Sweden	0.98	0.27	1.04	0.19
Switzerland	0.89	0.22	1.03	0.18
Tajikistan	0.02	0.22	0.07	0.22
Thailand	0.91	0.15	1.60	0.12
Timor-Leste	0.00	0.07	0.00	0.07
Togo	0.00	0.04	0.01	0.04
Tonga	0.00	0.07	0.00	0.05
Trinidad & Tobago	0.01	0.06	0.02	0.06
Tunisia	0.03	0.05	0.06	0.04
Turkey	1.73	0.18	3.82	0.16
Turkmenistan	0.02	0.10	0.12	0.13
Uganda	0.01	0.04	0.03	0.04
Ukraine	0.79	0.22	1.30	0.24
United Arab Emirates	0.57	0.18	1.29	0.20
United Kingdom	5.59	0.25	6.31	0.20
USA	29.28	0.21	35.58	0.17
Uruguay	0.07	0.17	0.11	0.15
Uzbekistan	0.13	0.18	0.50	0.21

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TABLE 3. VLW due to CNS cancer in USD (2017, PPP) and as a share of the GDP in 2000 and 2019 for 176 countries

Country	2000		2019	
	VLW (billion USD)	VLW/ GDP (%)	VLW (billion USD)	VLW/ GDP (%)
Vanuatu	0.00	0.08	0.00	0.07
Viet Nam	0.11	0.05	0.56	0.07
Zambia	0.01	0.05	0.03	0.05
Zimbabwe	0.01	0.03	0.01	0.04
Global	116.95	0.18	182.07	0.15

Three countries are missing from the year 2000 and 3 countries are missing from the year 2019, which leads to a total of 173 countries in each year.

this finding, global CNS cancer research funding has only just reached levels comparable to those for prostate cancer.^{38,39}

Our study has several limitations. First, the study relies on modeled rather than empirical data. As an example, VSL estimates of individual countries are modeled based on assumptions derived from data empirically generated in the US. This transformation may not accurately reflect regional variations; in an effort to minimize assumptions about willingness to pay after adjustment for economic

size and purchasing power, we selected an income elasticity of 1.0. Moreover, if country-specific willingness-to-pay assumptions are available to a reader, a supplemental analysis using IEs of 0.55 and 1.5 is provided in Supplemental Tables 2 and 3, respectively. Second, the only comprehensive set of DALY data used for the VLW model are aggregates of all malignant CNS tumors, which is problematic given the noted differences in clinical outcomes between high- and low-grade tumors and those of different tumor types. Finally, despite a global increase in availability of imaging modalities required for CNS cancer screening,⁴⁰ there is an absence of standardized screening protocols in LMICs; this likely contributes to a marked underestimation of the CNS cancer disease burden in LMICs.⁴¹

Conclusions

The present study represents what is to the authors' knowledge the first comprehensive report of macroeconomic losses associated with CNS cancer on a country-by-country basis. It is interesting to note that the global burden of CNS cancer appears to be influenced in part by geographic region. Mortality-to-incidence ratios were confirmed to be higher in low-income settings than in high-income settings, highlighting gaps in access to diagnosis and treatment. Finally, continued funding of novel diagnostic methods and clinical treatment paradigms is needed given the existing disparities and the increasing overall incidence and mortality of CNS cancer, which have been highlighted here as global concerns.

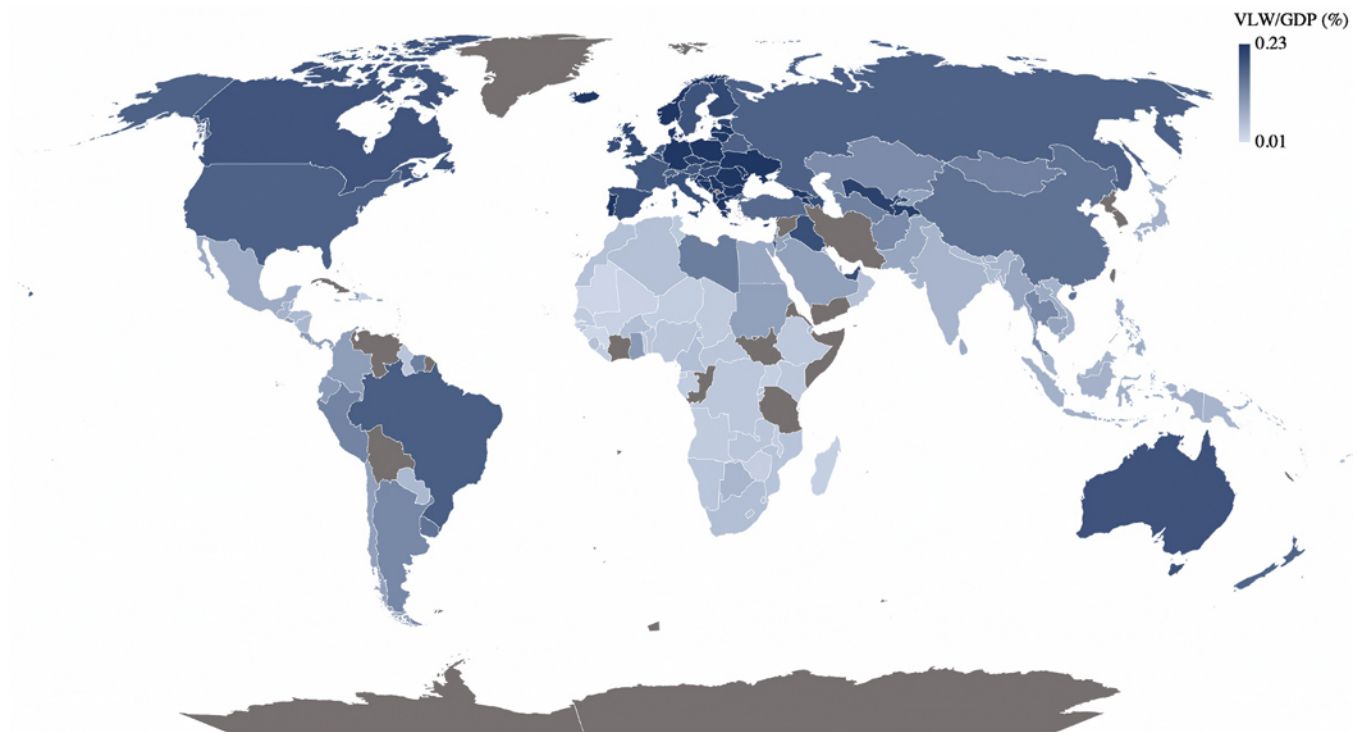


FIG. 1. Map showing the VLW as a percentage of GDP in 2019 (2017 USD, PPP). Countries lacking GDP data are shown in gray. The map was created using Microsoft Excel. Figure is available in color online only.

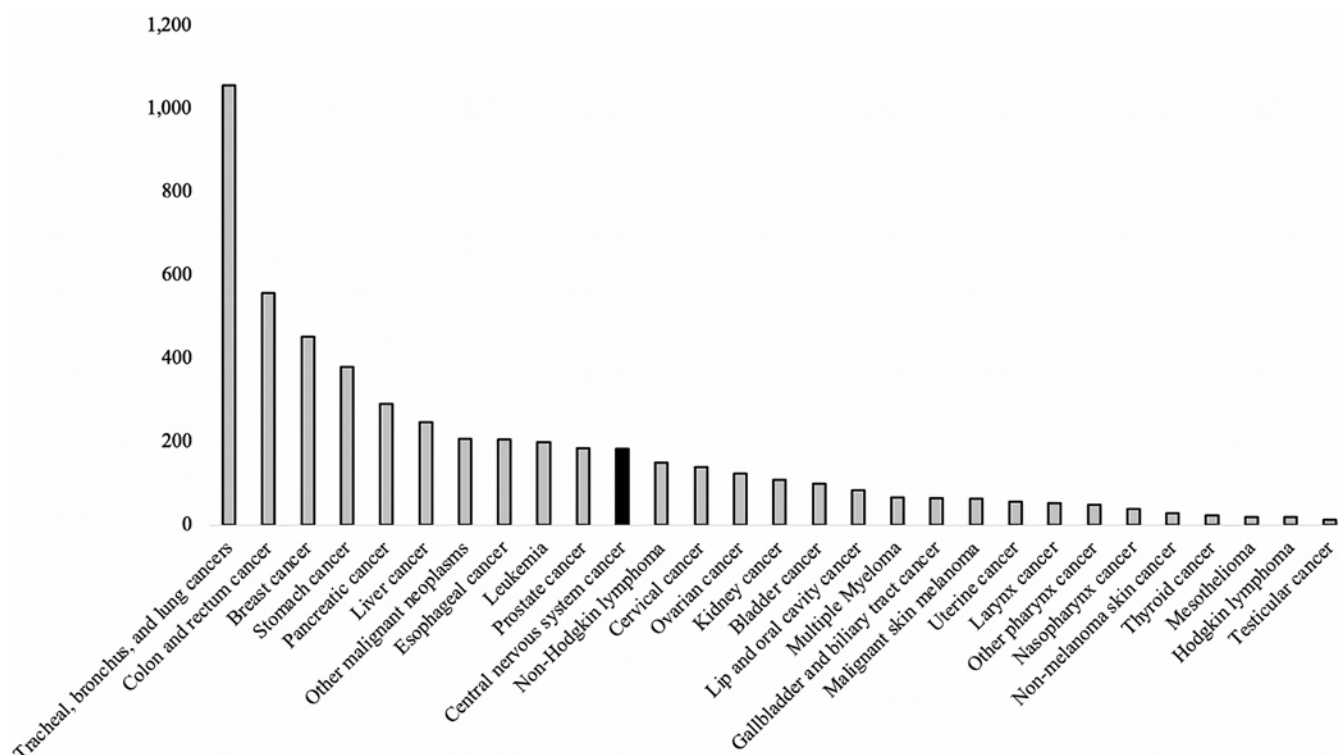


FIG. 2. Global VLW of oncological diseases in billion USD in 2019 (2017, PPP). Global CNS cancer losses are marked in black.

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Disclosures

Dr. Bernstock reports ownership of Treovir LLC and membership in the POKIT Diagnostics Board of Scientific Advisors. Dr. Smith reports being a cofounder and owner of PheBe Health Inc.

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Conception and design: Gerstl, Lassarén, Ranganathan. Acquisition of data: Gerstl, Yearley, Lassarén. Analysis and interpretation of data: Gerstl, Yearley, Kilgallon, Lassarén, Robertson, Segar, Smith. Drafting the article: Gerstl, Kilgallon, Lassarén. Critically revising the article: all authors. Reviewed submitted version of manuscript: Gerstl, Yearley, Kilgallon, Lassarén, Robertson, Herdell, Wang, Segar, Bernstock, Ranganathan, Smith. Approved the final version of the manuscript on behalf of all authors: Gerstl. Statistical analysis: Gerstl, Yearley, Lassarén, Herdell, Wang, Bernstock, Laws, Smith. Administrative/technical/material support: Gerstl, Kilgallon, Herdell, Wang, Bernstock, Laws, Ranganathan, Smith. Study supervision: Laws, Ranganathan, Smith.

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

Supplemental Tables 1–3. <https://thejns.org/doi/suppl/10.3171/2022.9.JNS221499>.

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