Public and philanthropic research funding, publications and research networks for cancer in the Commonwealth and globally in 2016-2023: comparative analysis

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Abstract

Background

Globally, cancer is responsible for one in five deaths. Research is crucial in providing new knowledge for patient care, policy and practice. The position of the Commonwealth countries in the global research funding and publication landscape was analysed.

Methods

We combined previously-labelled 2016-2020 data with new searches and analysis of human cancer research funding awarded from public and philanthropic funders 2021-2023, extracted from the Digital Science Dimensions database and Cancer Research UK website. Awards were categorised by cancer type, cross-cutting theme, and research phase. Awards labelling used machine learning algorithms, large language models, and manual scrutiny from cancer experts. Social network analysis examined the position of Commonwealth countries in international collaboration in cancer grant applications and publications.

Findings

We identified 107,955 cancer research awards, with total investment of $51.4 billion USD in 2016-2023. Annual investment decreased each year, apart from a rise in 2021.
Pre-clinical research received $39.0 billion (76.0% of funding), phase 1–4 clinical trials receiving $3.7 billion (7.3%). Breast ($5.3billion, 10.3%) and hematological cancer ($4.7 billion, 9.0%) were well-funded. Surgery research ($0.8 billion, 1.7%) and radiotherapy research ($1.6 billion, 3.1%) were underfunded. In the Commonwealth, the UK, Australia, and Canada were lead contributors and receivers of cancer funding. Low-income countries worldwide received less than 0.1% of total funding. Network analysis revealed close collaborations between a core of high-income Commonwealth countries, that facilitated knowledge exchange between lower-income Commonwealth countries, the US and European Union countries.

Interpretation

Within Commonwealth countries and globally, funding is concentrated in high-income countries. Greater research funding with local leadership should be allocated to lower-income countries that have limited resources to address cancer burden. Investment in cancer research on other treatment modalities, including surgery and radiotherapy, also needs to be prioritised to improve patient benefits.

Summary
This study presents a comprehensive analysis to report the amounts and distribution of public and philanthropic global cancer research funding 2016-2023 as well as the patterns of international collaboration in funding and the downstream research outputs, with a specific emphasis on the Commonwealth. We demonstrate that annual investment decreased each year globally, apart from a rise 2021. Network analysis revealed that grant and publication collaborations between the Commonwealth, US and Europe is facilitated by linkages through a core of Commonwealth countries around the UK, Australia, and Canada. There are inequities in research investment and low funding for treatment modalities for many cancers. The inequities also manifest in the central positioning of higher income Commonwealth countries in research collaborations, but also points to opportunities for these countries to facilitate linkages between lower-income countries and active cancer research in the US and Europe. There is an urgent need to review research investment priorities both in the Commonwealth and globally to align with population needs and promote collaboration strategies that can build research skills and infrastructure in low-income settings to impact global cancer control. Finite resources must be invested wisely to achieve maximum improvements in mortality and alleviate the cancer burden.

Introduction

The incidence of cancer is rising globally, and cancer is the second most common cause of death worldwide responsible for one in five deaths.[1] The Global Cancer Observatory (GLOBOCAN) estimated around 10 million cancer deaths and 20 million new cases in 2022, projected to rise to 18 million deaths and 35 million new cases by 2050.[1] The proportional increase in cancer incidence is especially pronounced in low-income countries, where it is estimated to be 142% by 2050 compared to 2022.[1] Research is integral to improving outcomes for people with cancer, by generating new knowledge for improving cancer control, clinical practice across the care continuum and policy. Better treatments following successful research have improved cancer outcomes.[2] Evidence on the landscape of cancer research investment is essential to better allocate available resources equitably and efficiently to optimise health outcomes globally.

Prior research on global cancer research investment landscape has primarily focused on specific geographies or a relatively small proportion of funding bodies. We conducted a comprehensive analysis of public and philanthropic investment in cancer research from 2016 to 2020 that was published by *The Lancet Oncology*.[3] This study revealed misalignment of research funding and cancer burden, decreasing investment over time, a strong focus on pre-clinical awards, and low levels of investment in research directly involving patients, and low-income countries.

Recent bibliometrics analyses of cancer research outputs highlighted trends and advancements in applications of deep learning in cancer,[4] cancer radiomics,[5] cancer photodynamic therapy,[6] but these studies were mostly non-patient facing and in early phase research. Studies have also examined contributions and collaboration patterns of leading countries and institutions in cancer research,[4,6,7] where the US and China emerged as leaders in various aspects of cancer research. However, there was a lack of evidence of LMIC involvement in such collaborations.[4,6,7] In this co-authorship analysis of the research collaboration between 54 African countries and the world,[8] the authors highlighted power imbalances between African countries and Western countries reflected in the authorship positions and urged for more intra-African partnerships in research.

The Commonwealth, as an intergovernmental organization of 56 countries spanning diverse regions and income levels, seeks to improve cooperation, equity, and capacity-building among its member states. This includes a focus on improving health outcomes and reducing disparities.[9] In 2020, the Commonwealth was estimated to account for 14.3% of the global incidence of 11 common cancers in 2020, a figure projected to increase to 17.3% by 2050.[10] Alongside this growing burden, the 5-year net survival rate for these cancers showed marked disparities across the Commonwealth, ranging from 4.1% in low-income countries to 17.8% in low-middle-income countries, 33.1% in upper-middle-income countries, and 59.0% in high-income countries.[10] These findings call for a Commonwealth-wide initiative to mobilise knowledge and resources for improved treatment access and care quality. Therefore, a crucial first step is to re-examine the Commonwealth's role in cancer research collaborations to support efforts towards an equitable distribution of resources and investment.

In this manuscript, we examined the position of the Commonwealth within the global research landscape, using established methodology.[3,11] We conducted a systematic analysis of global public and philanthropic cancer research funding over an 8-year period from 1 January 2016 to 31 December 2023. Utilizing a novel combination of automated analysis methods, which included machine learning algorithms and Large Language Models (LLM), and expert input we categorized awards into research themes and phases of research defined in previous work.[3] The amount of funding for awards were examined relative to global burden of disease, total gross domestic product (GDP) income, and population metrics. In addition, the landscape of publications produced by the cancer research funding was examined to gain insights in collaborations in the ecosystem of cancer research.

Method

Data sources, search strategy and selection criteria

We applied previously adopted search strategies that combined cancer-related keywords and filters to retrieve details of all global cancer research awards in English between 2021.01.01 and 2023.12.31 from the Digital Science Dimensions database.[3,11] Dimensions describes itself as providing the world's largest collection of linked research data, containing 7 million grants and 146 million publications (as of January 2025), both health-related and non-health related.[12] The retrieved awards included those with pre-assigned labels of Health Research Classification System (HRCS) related to cancer and those with a set of cancer keywords in award title or abstract. The publications linked with the awards were also retrieved. (Appendix p2)

Data labelling pipeline

Following previous work,[3] the retrieved awards were assessed to confirm their inclusion as related to cancer research, and classified in terms of cancer type (e.g. breast, liver, thyroid), metastatic disease (yes/no), patient age group (child, adult, elderly, all, not applicable), cross-cutting theme (e.g. cancer biology, global health), and phase of research. The phases were: pre-clinical (laboratory-based); phase 1–4 clinical trials; public health (population-based, epidemiological, behavioural, and implementation research); or cross-disciplinary (spanning multiple research phases, such as progressing from pre-clinical to phase 1). See Appendix pp2-3 for detailed definitions.

The categorisation of each individual award (Appendix Fig A1, p4) combined machine learning algorithms and manual human scrutiny and labelling. Automated approaches were developed by co-authors BZ and AD. These included tailored prompting of an LLM and supervised learning via training Random Forests (RF). Compared with previous work that usually took months of manual labelling, the automated approaches have allowed for a significant speed-up of the entire process, with no discernable difference in the quality of labelling.

LLMs are generative models that were trained on extensive textual information and thus capable of understanding context and providing detailed, meaningful responses. LLMs were selected (Appendix p5) due to their demonstrated ability to classify medical text data.[13] Random Forests are machine learning models that combine the power of many decision trees—simple models that make decisions by asking a series of "yes" or "no" questions—to make better predictions. They were selected due to their known robustness in classification tasks.[14] The LLM prompts and RFs were optimised for precision through prompt engineering and hyperparameter tuning. For model implementation and performance, see the appendix pp5-10.

For each category of the awards (including inclusion/exclusion, cancer type, metastatic disease, patient age group, cross-cutting theme, and phase of research) where the automated categorization resulted in a precision below 0.80, entries were flagged for manual scrutiny. The 0.80 threshold was decided by consensus within the core study team as a pragmatic benchmark. Therefore, all relevant awards, 37300 in total, were shared with 13 co-authors to examine inclusion/exclusion and complete other classifications. Where there were awards with queries or still needing to be labeled, these were completed through advanced keyword matching strategies and manual scrutiny (Appendix pp10-12). Evaluating automated approaches versus human labelling we found an average agreement rate of 92% (confidence interval 87-96%). See Appendix p13 for details.

Estimation of missing awards and inflation adjustment

Funding amount was missing from 8604 (20.7%) of the final 41567 individual awards from 2021-2023, totaling $1.0 billion (4.4% of total investment 2021-2023 inclusive). Missing amounts were estimated by reviewing likely award amounts for this type of award on the funder website and by previous written communications with principal investigators and funders. Cancer Research UK do not provide individual award funding data. We estimated their expenditure using annual reports from 2021 to 2023 inclusive,[15] repeating methods used previously by the study team.[3]

All awards were adjusted for inflation in original currency and converted to 2023 US$ using the mean exchange rate in the award year. All awards from 2021 to 2023 were combined with 2016-2020 awards from the prior study[3] for analysis. Associated publications from the awards from 2016-2023 inclusive were retrieved.

Country

Retrieved metadata of a grant contained two fields related to country information: (i) funder country indicating the source country for the funding, and (ii) the country of the affiliated institution of principle investigator, indicating in what country the grant was invested. Note that we assume that funding in each grant flows to the PI affiliated country rather than co-I countries. Retrieved metadata of a publication contained location information of author affiliations. Number of publications from each country (Table 1) counts the number of publications a country was involved in in the list of authors' affiliated countries.

The Commonwealth (CW), as the subject of analysis in this work, was compared with other economic and political groups of countries including the European Union (EU), the BRICS (BRICS), and the Group of Seven (G7). The total funding amount from and invested into these groups was compared in Table 1 and Fig 1. We used the ISO 3166-1 alpha-2 country code system to represent individual countries (e.g. GB for the UK, DE for Germany, see detail in Table A11, appendix pp19-25).

Network Analysis

Network representations of publication or grant activity are an established tool to quantify research collaborations.[16–18] Accordingly, to capture collaborations between Commonwealth and other countries in cancer research, we used the curated grant and publication database to construct collaboration networks indicating co-relationships based on publication and grant activity. In these networks, nodes represent countries and links indicate co-occurrence of countries in either author lists in publications or Principal Investigator and Co-Investigator lists associated with funding awards. As also in other contexts for worldwide research collaboration analysis,[7,16,19] we used binary counting to measure total co-involvement of countries over a given period of time. This measure counts how often countries were involved together in a publication output or grant award and yields an overall connection strength between countries. As this measure is heavily biased towards countries that produce large amounts of publications or funding awards, we also measured collaboration intensity per publication or award, using normalisation by so-called cosine similarity.[20–22] In the resulting normalised networks, connection weights can be understood as a measure of connection strength per activity, i.e. if a paper is written with one countries' involvement, the link weight is related to the likelihood that linked countries will be co-involved in the paper.

Analysing total activity count networks gives insights into total activity patterns in a given time period and can be seen as a measure of actual activity in grant acquisition or research dissemination. On the other hand, analysing networks based on activity normalised by cosine similarity, additionally gives insights into activities of countries that only produce relatively little funding or publication output and quantifies collaboration intensity per activity. These networks could be interpreted as networks of research potential indicating likely collaboration partners, provided opportunities were available.

Using the procedure described above, funding collaboration networks based on total activity and normalised activity were compiled for the time periods 2016-2020 and 2021-2023. Publications are usually produced over a period of time from the reception of an award on and publication activity related to an award may then extend over several years beyond the duration of the award.[23] To avoid bias in publication analysis from very recent awards in the 21-23 time period, publication data were only considered aggregated for the entire time period 2016-2023, limited to publications related to funding awards.

Networks were then processed, analysed for community membership[24,25] using Gephi[26] and the networkX package for python[27] and visualised using the Pajek software[28] based on force-directed graph layout by the Kamada-Kawai algorithm[29] and manual adjustments of the network projections to avoid node overlaps. Nodes in the networks represent countries labelled by country code (Table A11, appendix pp19-25). Node colourings reflect community membership as determined by modularity analysis, where the resulting significance of the modularity measure was reported in corresponding figure captions. This allowed the determination of subgroups of countries that have significantly more links to countries belonging to their own grouping than to other nodes. The groupings reflect groups of countries that collaborate significantly more with each other than with other countries outside of the group. In visualisations, link weights were indicated by shades of grey with dark colours representing the strongest weights and light colours weak links. We noted that all networks are generally characterised by very heterogeneous link weight distributions with many weak relationships and few dominant very strong connections.

We then analysed nodes for centrality, based on node strengths[30] and PageRank[31]. Analysis by node strength allows to identify countries that are important because they have many strong connections to other countries. In contrast, PageRank allows for more detailed analysis which measures importance in the research network by also accounting for the importance of the countries a country collaborates with. PageRank thus favours countries with strong connections to other important countries. Results of the centrality analysis of publication and grant-based networks based on node strength and PageRank were reported in table 2 with additional information provided in table A9 (appendix pp13-14). As a limitation, we noted that network measures tend to fluctuate if activity involvement of countries is relatively low. This is the case for many lower-income countries which have relatively minor involvement in overall publication activity and in funding awards. Consequently, centrality measures in particular for lower-income countries can depend on relatively few papers or grants and thus vary considerably between time periods.

Burden of disease

Burden of disease data up to 2021, specifically disability-adjusted life years (DALYs), were sourced from the Global Burden of Disease (GBD) study.[32] Population and GDP (total GDP with purchasing power parity in constant 2021 international $) data from 2016-2023 were sourced from World Bank Open Data portal.[33] We examined funding per DALY, funding per Population and funding per GDP in Table 1 and Fig 1. Funding per DALY serves as a proxy for investment level relative to disease burden. Funding per Population and per GDP serve as a proxy for investment level relative to economic and population size.

Software

OpenAI's GPT4o-mini batch mode was used for automatic data labelling. We used scikit-learn 1.5.2 to build the RF. We used Python 3.11.9 for data extraction, pre-processing, model training and testing, data labelling, data analysis and visualisation.

	Num. Awards (Source)	Funding source, $ (%)	Median source, $ (IQR)	Mean source, S (SD)	Num. Pub
Countries (CRUK included)					
AU	1,787(1.7%)	1,503,590,009(2.9%)	564,847(337,611-845,167)	845,664(2,133,491)	14,775(3.4%)
CA	6,878(6.4%)	1,348,980,522(2.6%)	80,767(26,127-171,639)	200,861(483,521)	11,507(2.7%)
CN	15,648(14.5%)	1,319,253,058(2.6%)	68,419(35,695-101,994)	84,308(145,109)	158,136(36.6%)
EC	1,808(1.7%)	3,573,870,184(7.0%)	299,636(206,177-2,705,628)	1,979,983(2,978,384)	
DE	2,495(2.3%)	711,823,006(1.4%)	128,435(109,246-136,348)	289,477(1,426,796)	22,219(5.1%)
JP	21,176(19.6%)	1,863,699,397(3.6%)	44,618(33,426-49,241)	88,524(382,682)	58,797(13.6%)
GB	6,071(5.6%)	5,698,465,140(11.1%)	234,723(147,367-550,313)	583,493(1,541,468)	32,420(7.5%)
US	29,528(27.4%)	29,391,067,563(57.2%)	548,332(237,435-1,281,610)	995,497(1,615,258)	184,906(42.8%)
Other	22,564(20.9%)	6,003,582,141(11.7%)	131,956(4,0873-340,812)	270,822(604,253)	103,488(24.0%)
Blocks of countries (CRUK included)					
CW	15,656(14.5%)	8,731,361,231(17.0%)	153,915(55,110-447,625)	422,119(1,268,808)	58,463(13.5%)
EU	17,630(16.3%)	8,638,644,532(16.8%)	171,457(109,246-433,325)	498,997(1,343,094)	80,335(18.6%)
BRICS	22,225(20.6%)	1,600,756,871(3.1%)	42,745(34,605-99,540)	72,360(135,395)	172,316(39.9%)
G7	67,537(62.6%)	39,488,380,233(76.8%)	161,099(46,013-592,215)	555,358(1,292,536)	270,558(62.7%)
income level (CRUK included)					
L	0(0.0%)	0(0.0%)	0(0-0)	0(0)	832(0.2%)
LM	478(0.4%)	56,518,249(0.1%)	81,106(52,906-130,580)	147,567(366,787)	7,624(1.8%)
UM	20,670(19.1%)	1,471,047,967(2.9%)	42,745(35,000-99,540)	71,175(128,686)	170,155(39.4%)
H	86,807(80.4%)	49,886,764,801(97.0%)	178,077(47,659-553,699)	553,736(1,312,342)	308,936(71.6%)
year of award (CRUK included)					
2016	14,062(13.0%)	7,749,254,709(15.1%)	120,195(49,591-457,192)	521,058(1,262,068)	7,901(1.8%)
2017	13,910(12.9%)	6,530,509,824(12.7%)	114,128(47,873-422,656)	460,917(1,349,908)	20,371(4.7%)
2018	15,063(14.0%)	6,362,318,987(12.4%)	103,516(44,147-382,261)	403,933(1,013,057)	35,613(8.2%)
2019	13,324(12.3%)	4,677,768,865(9.1%)	99,539(44,618-286,606)	328,956(1,118,241)	51,012(11.8%)
2020	10,029(9.3%)	3,427,192,367(6.7%)	89,331(44,855-290,545)	313,910(1,328,746)	65,016(15.1%)

2021	14,527(13.5%)	9,134,134,123(17.8%)	170,233(42,715-621,040)	617,240(1,243,707)	72,773(16.9%)
2022	14,380(13.3%)	7,404,344,568(14.4%)	144,182(35,578-557,827)	503,993(1,055,806)	67,455(15.6%)
2023	12,660(11.7%)	6,128,807,571(11.9%)	148,148(34,232-535,192)	474,094(1,154,541)	61,026(14.1%)
funder					
NIH	19,166(17.8%)	21,896,423,010(42.6%)	665,774(318,964-1,553,350)	1,142,461(1737226)	162,545(37.6%)
Canadian Institutes of Health Research	2,955(2.7%)	710,138,951(1.4%)	87,312(16,394-320,611)	242,120(390,316)	3,441(0.8%)
European Commission	1,255(1.2%)	2,628,852,387(5.1%)	264,353(218,497-2950,904)	2,098,046(3,428,458)	27,984(6.5%)
German Research Foundation	1,921(1.8%)	237,996,235(0.5%)	128,435(109,246-133,221)	124,150(11,249)	9,680(2.2%)
Japan Society for the Promotion of Science	19,540(18.1%)	1,154,433,312(2.2%)	43,936(33,307-47,406)	59,353(164,352)	54,899(12.7%)
National Health and Medical Research Council	1,186(1.1%)	1,005,804,748(2.0%)	613,405(439,601-855,585)	850,215(1,239,702)	8,905(2.1%)
National Natural Science Foundation of China	14,802(13.7%)	1,189,087,871(2.3%)	61,120(35,695-101,285)	80,332(141,055)	144,821(33.5%)
Medical Research Council UK	1,015(0.9%)	770,691,583(1.5%)	341,131(153,915-911,578)	761,552(1,030,877)	12,556(2.9%)
Wellcome Trust	336(0.3%)	336,641,585(0.7%)	353,266(3,397-1,627,351)	1,001,909(1,708,047)	9,357(2.2%)
Cancer Research UK		2,444,322,770(4.8%)			10,563(2.4%)
cancer sites (CRUK included)					
bladder	1,205(1.1%)	448,631,678(0.9%)	75000(36633-324,336)	357,083(801,404)	6,150(1.4%)
bone	1,279(1.2%)	494,440,139(1.0%)	99539(39054-304,998)	371,994(1,029,859)	5,880(1.4%)
brain	6,333(5.9%)	3,103,959,279(6.0%)	144,893(46,256-500,174)	468,981(880,518)	29,797(6.9%)
breast	10,758(10.0%)	5,274,268,986(10.3%)	129,440(44,618-517,285)	465,888(943,447)	57,423(13.3%)
cancergeneral	31,589(29.3%)	16,480,818,556(32.1%)	136,348(45,743-484,056)	528,824(1,567,699)	180,465(41.8%)
cervical	1,146(1.1%)	429,681,489(0.8%)	69,817(36,672-314,654)	365,383(856,120)	4,781(1.1%)
cholangiocarcinoma	275(0.3%)	49,298,923(0.1%)	510,08(39,054-130,685)	181,246(468,976)	2,093(0.5%)
colorectal	5,420(5.0%)	2,259,251,432(4.4%)	99,539(41,551-365,748)	363,683(931,054)	32,727(7.6%)
haematological	8,841(8.2%)	4,651,455,777(9.0%)	159,597(53,297-541,125)	496,572(1,252,226)	35,273(8.2%)
headandneck	4,184(3.9%)	1,291,541,918(2.5%)	47,873(36,698-188,975)	301,496(752,220)	19,276(4.5%)
liver	4,011(3.7%)	1,249,860,630(2.4%)	94,203(37,846-184,478)	300,844(733,175)	30,793(7.1%)
lung	5,647(5.2%)	2,405,524,975(4.7%)	97,793(40,605-299,108)	378,012(891,072)	39,374(9.1%)
mesothelioma	242(0.2%)	83,156,539(0.2%)	108,055(43,811-389,098)	349,397(716,145)	964(0.2%)

multiple	6,704(6.2%)	4,122,265,357(8.0%)	166,963(48,286-553,698)	624,396(1,497,926)	46,756(10.8%)
other	1,358(1.3%)	674,607,911(1.3%)	85,621(42,744-308,248)	347,908(861,736)	7,714(1.8%)
ovarian	2,343(2.2%)	1,041,949,488(2.0%)	108,750(43,989-464,631)	405,295(837,777)	12,578(2.9%)
pancreatic	3,852(3.6%)	1,766,873,229(3.4%)	103,814(43,770-371,246)	415,352(975,773)	22,653(5.2%)
prostate	4,378(4.1%)	2,518,351,913(4.9%)	189,458(49,241-727,983)	545,218(897,721)	21,908(5.1%)
renal	1,298(1.2%)	567,541,299(1.1%)	109,189(39,054-454,402)	400,476(822,062)	6,435(1.5%)
skin	2,756(2.6%)	1,369,940,138(2.7%)	160,535(46,256-520,971)	472,896(938,512)	14,787(3.4%)
testicular	93(0.1%)	28,112,628(0.1%)	127,804(46,256-457,507)	308,929(408,351)	374(0.1%)
thyroid	710(0.7%)	177,906,130(0.3%)	47,156(35,000-145,514)	240,277(508,564)	2,907(0.7%)
uppergi	3,532(3.3%)	924,849,158(1.8%)	50,000(35,695-116,818)	231,826(660,928)	22,112(5.1%)
cross-cutting					
biomarkers	4,067(3.8%)	1,689,429,131(3.3%)	105,608(43,924-398,779)	422,357(1,189,226)	33,016(7.6%)
cancerbiology	47,601(44.1%)	19,343,022,392(37.6%)	107,086(43,453-406,626)	410,427(1,149,676)	233,495(54.1%)
diagnosisscreeningandmonitoring	9,991(9.3%)	5,567,235,529(10.8%)	145,950(46,256-526,038)	568,317(1,289,203)	65,618(15.2%)
drugtreatment	20,628(19.1%)	8,755,158,038(17.0%)	112,308(42,715-425,847)	428,964(1,176,487)	116,893(27.1%)
globalhealth	822(0.8%)	937,302,589(1.8%)	444,701(100,229-1,287,296)	1,151,477(2,369,606)	3,971(0.9%)
immunology	14,221(13.2%)	7,732,043,873(15.0%)	162,319(47,538-568,258)	548,255(1,235,661)	66,476(15.4%)
psychosocial	4,911(4.5%)	2,475,969,515(4.8%)	124,100(38,629-485,050)	510,825(1,101,618)	15,741(3.6%)
radiotherapy	3,780(3.5%)	1,581,753,598(3.1%)	105,401(40,873-419,125)	424,745(1,062,015)	20,541(4.8%)
surgery	1,934(1.8%)	888,093,578(1.7%)	109,017(36,486-447,245)	466,190(1,131,718)	7,700(1.8%)
phase of research					
crossdisciplinary	2,131(2.0%)	2,024,817,402(3.9%)	342,447(81,046-949,741)	963,739(2,889,623)	21,434(5.0%)
clinicaltrial	4,423(4.1%)	3,731,738,862(7.3%)	324,184(65,484-914,793)	861,236(1,756,764)	16,719(3.9%)
preclinical	94,330(87.4%)	39,072,246,788(76.0%)	112,121(43,453-425,499)	418,493(1,041,109)	396,142(91.8%)
publichealth	7,071(6.5%)	4,141,205,193(8.1%)	123,858(42,402-506,516)	597,576(1,622,445)	32,191(7.5%)
age					
adult	6,530(6.0%)	4,224,042,467(8.2%)	183,192(46,906-637,347)	656,314(1,357,097)	42,612(9.9%)
all	5,079(4.7%)	2,836,983,675(5.5%)	109,763(46,012-488,514)	562,781(2,065,414)	46,578(10.8%)

childhood	5,579(5.2%)	3,151,862,906(6.1%)	197,691(57,952-553,698)	572,545(1,237,065)	16,366(3.8%)
elderly	1,465(1.4%)	911,881,460(1.8%)	166,594(40,873-554,944)	629,317(1,495,687)	5,661(1.3%)
notapplicable	89,302(82.7%)	37,845,237,737(73.6%)	110,949(42,744-430,250)	428,612(1,097,483)	384,151(89.0%)
metastatic					
yes	11,927(11.0%)	4,934,360,260(9.6%)	105,636(43,770-461,840)	416,190(863,849)	73,335(17.0%)
no	96,028(89.0%)	44,035,647,986(85.6%)	120,082(43,936-449,814)	464,158(1,227,692)	401,367(93.0%)
covid-related					
covid	166(0.2%)	66,472,892(0.1%)	130,750(38,871-296,008)	402,866(815,405)	322(0.1%)
notcovid	107,789(99.8%)	48,903,535,354(95.1%)	116,817(43,936-451,018)	458,916(1,193,351)	431,518(100.0%)

Table 1. Breakdown of global research investment and number of publications linked to the investment. Total awards: 107955. Total funding $51.4 billion USD. Total publications: 431733. Funding allocation from sources (e.g. country of funder) and funding allocation to targets (e.g. country of receiving lead institution) were reported. IQR, inter-quartile range. SD, standard deviation. AU-Australia, CA-Canada, CN-China, DE-Germany, JP-Japan, GB- United Kingdom, US-United States. EC stands for European Commission. CW stands for the Commonwealth. BRICS stands for the five-country version of the BRICS. G7 stands for the G7 countries.

Result

Global Cancer Research Funding Landscape Overview

The final dataset included 107955 awards for cancer research between 2016 and 2023 inclusive, with total investment of $51.4 billion. This includes 66388 awards with total investment of US$28.7 billion ($24.5 billion before inflation adjustment) in 2016–20, as described previously,[3] and 41567 awards ($22.7 billion) awarded 2021-23 inclusive. The downstream output linked within Dimensions to included awards comprised 431.7 thousand publications. See table 1 for more details.

The USA provided the highest amount of funding of $29.3 billion (57.2%), including the single biggest funder, $21.9 billion (42.6%) the US National Institute of Health ($21.9 billion, 42.6%). The Commonwealth (CW) collectively provided $8.7 billion funding (17.0%), with the leading contributors including the UK ($5.7 billion, 11.1%), Australia ($1.5 billion, 2.9%) and Canada ($1.3 billion, 2.6%). Globally, funders in high-income countries contributed $50.0 billion (97.0%).

High-income countries demonstrated stronger research investment per cancer-associated DALY: US ($1852.2/DALY), UK ($1556.7/DALY), Australia ($1334.5/DALY). The CW collectively contributed $165.0/DALYs, with only the BRICS group contributing less at $14.0/DALY. Low-income countries received sum investment of $8.4 million (<0.1%), with $0.7/DALY (Table A12, appendix p25). Similar disparity between high- and low-income countries was also observed in the received investment (as PI-affiliated countries) per capita (high-$36.57/capita, low-$0.01/capita) and per GDP (high-$0.00080/GDP, low-$0.00002/GDP) (Table A12, appendix p25).

By country of affiliation, USA-based institutions were involved in 184906 publications (42.8%), followed by China (158136, 36.6%) and Japan (58797, 13.6%). The CW collectively contributed to 58463 publications (13.5%), with the UK (32420, 7.5%) being the highest CW contributing country. In terms of income level, institutions in high-income countries were involved in 308936 publications (71.6%), in contrast to low-income countries' involvement (832 publications, 0.2%).

Breakdown by Nature and Phases of Research

By type of science, $39.0 billion (76%) of global investment in cancer research focused on preclinical science. Phase 1-4 clinical trials received $3.7 billion (7.3%). In terms of cancer sites, general cancer (i.e., no cancer site specified) received $16.5 billion (32.1%). Breast cancer ($5.3 billion, 10.3%) was the most highly funded site-specific cancer research. In terms of cross-cutting themes, excluding Cancer Research UK, $19.3 billion (37.6%) was invested on cancer biology research. Radiotherapy ($1.6 billion, 3.1%) and surgery ($0.8 billion, 1.7%) accounted for small proportions of total research investment.

Annual Investment Trend

Except for a sharp increase in 2021, annual cancer research investment showed a decreasing trend over time (Fig.1(a), Table 1). The annual investment in Commonwealth countries over time largely followed the global trend (Fig. 1b).

The USA played a dominant role in both the G7 and the global investment trend, followed by the UK (Fig1a, c). EU annual investment has risen since 2021 (Fig1.b), likely due to Germany's post-2020 investment increase (Fig1.d). This was mainly driven by increased contributions from the Federal Ministry of Education and Research. BRICS, accounting for a lesser proportion of global cancer research investment, showed a rise leading up to 2018 (Fig1b), with a subsequent decline in annual investment, mirroring the trend of China (Fig1c, d).

By country grouping, analyses of investment per GDP (Fig1e) revealed highest annual spending from the US (above 10^{-4}\$/GDP), followed by the EU (around 10^{-4}\$/GDP) and Commonwealth (below 10^{-4}\$/GDP), and then the BRICS (below 10^{-5}\$/GDP). Investment per GDP in the Commonwealth was led by the UK (well above 10^{-4}\$/GDP), Australia (above 10^{-4}\$/GDP), and Canada (around 10^{-4}\$/GDP) (Appendix FigA5b, p19).

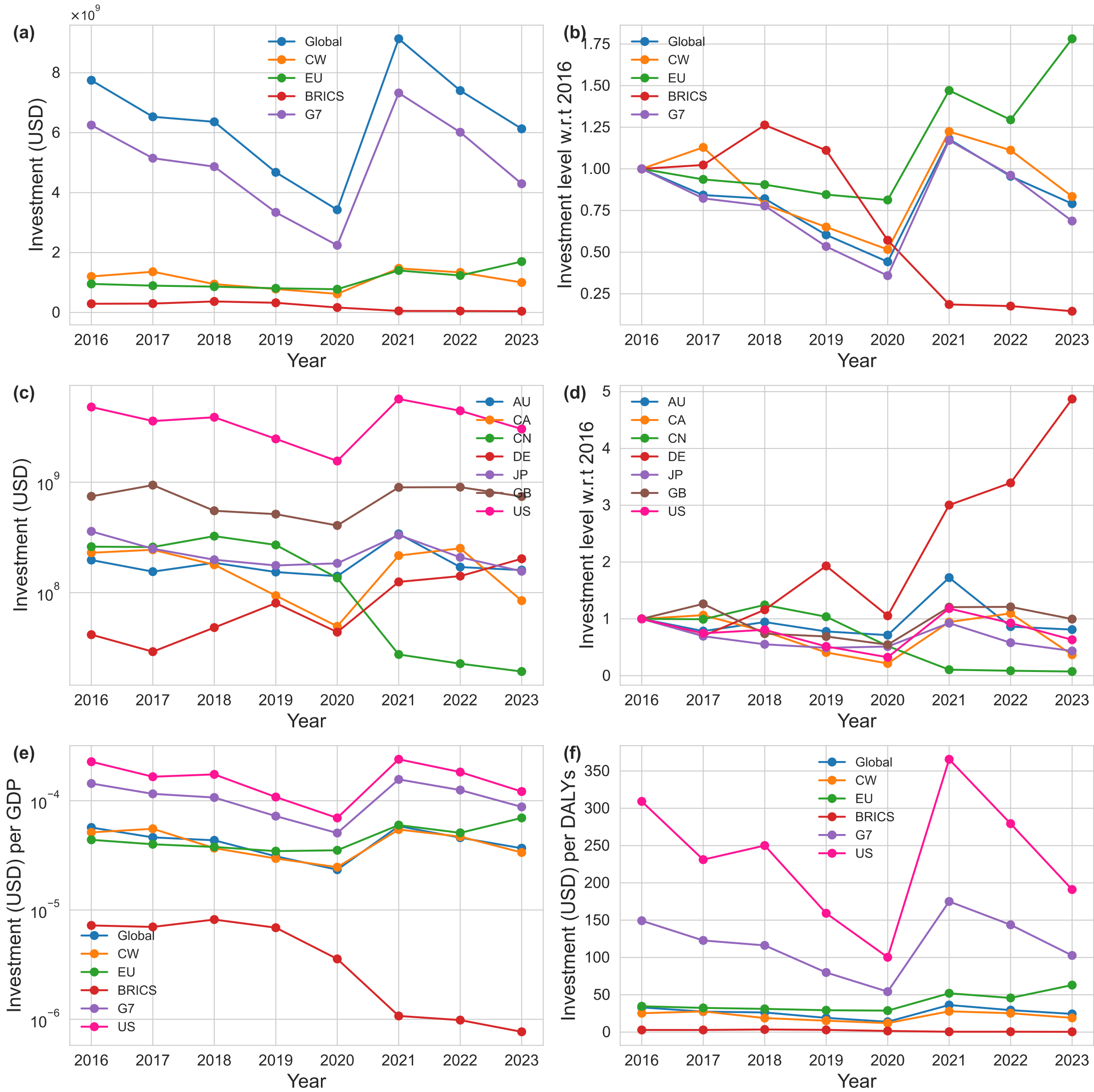

Fig1. Total Annual Investment on Cancer Research. (a) Total annual investment from groups of countries. (b) Relative investment level as a proportion to 2016 investment from groups of countries. (c) Total annual investment from individual countries. (d) Relative investment level as a proportion to 2016 investment from individual countries. (e) Total annual investment per GDP (total GDP with purchasing power parity in constant 2021 international $). (f) Total annual investment per DALYs (DALYs for 2022, 2023 was not available and set to 2021 DALYs).

International Collaboration Networks

Network visualisations showing worldwide publication co-authorship relations and grant-collaboration relationships for all recorded countries are shown in Figs. A2 and A3 in the Appendix, pp 16-17.

For the publication analysis, based on total publication activity (Fig A2(a)), we identified a rich club like structure with a core group of high-income countries around the US (yellow) and a large group of countries at the periphery of the network (green) with an overall modularity measure of m=0.06. Links in total activity publication networks were dominated by the US-China relationship and relationships between high-income countries including European countries and Australia and Canada.

In contrast to the total activity-based network, the normalised network in Fig A2(b) exhibited a far more prominent community structure (modularity m=0.19) and revealed the emergence of other groupings of countries. We noted groups of countries representing the "west" and China lead by the US, UK, Germany, and China (yellow), a former Soviet Union grouping including Eastern-European countries lead by Poland, Czechia, and Russia (cyan) and a grouping representing the rest of the world lead by Brazil, South Africa, and India (green). The visualisation in Fig A2(b) also made it apparent that linkages in the grouping around China, the US, the UK, and Germany are particularly dense. We also noted that the Commonwealth does not emerge as a distinctive group in publication analysis, with high-income Commonwealth countries being members of the US-centric block and lower-income Commonwealth countries being part of the Brazil, South Africa, India subgrouping.

Measuring degree strength and PageRank,[30,31] Commonwealth countries were then analysed to assess their centrality in co-funding and co-authorship networks (Table 2). Country position in co-authorship networks roughly correlated with positioning in co-funding networks. Ranking analysis again shows dominance of the UK, Australia, and Canada. However, there is an important role of African Commonwealth countries like South Africa or Nigeria in establishing collaborations within Africa- this is reflected in positions in per-activity based networks that are much stronger than in networks based on total count (Table A13, appendix p26). When comparing involvement in funding activity between the 2016-20 and 2021-23 periods the UK's and Australia's per activity-based positions have markedly declined, reflecting weakened breadth of these countries' engagement to the rest of the world.

	grants		papers	
	strength	PageRank	strength	PageRank
UK	1->4	1->4	2	2
Australia	13->19	15->23	10	10
Canada	18->16	31->25	12	12
India	8->55	10->61	27	25
New Zealand	29->32	38->38	58	63
Malaysia	49->29	54->31	46	45
South Africa	31->43	29->26	25	23
Nigeria	36->36	18->19	45	35
Singapore	61->71	61->72	29	29
Pakistan	80->62	73->51	42	41
Cyprus	71->54	78->68	69	74
Uganda	24->50	40->35	48	39
Kenya	79->47	65->46	37	32
Bangladesh	64->72	51->71	52	54

Tanzania	89->84	76->65	51	42
Zimbabwe	45->85	47->64	85	62

Table 2: The relative standing of Commonwealth countries in the 2016-2020 and 2021-2023 per-activity funding networks out of 94 and 90 countries, with links defined by cosine similarity, comparing degree strength and PageRank for the two time periods 2016-20 and 2021-23 (separated by "->" to indicate change between time periods). Relative standing of Commonwealth countries in the per-activity co-authorship network 2016-2023 were also reported.

For better illustration of collaborations within the Commonwealth, we also grouped non-Commonwealth countries into clusters (Fig. 2). Networks constructed by total activity again revealed core-periphery structure around a UK, Canada, Australia-dominated centre with strong links to the US and the EU. The per activity-based networks showed other subgroupings. Regarding co-authorship (Fig2 (a,b)), an African-centric group of countries was led by South Africa, Nigeria, Kenia, and Tanzania, and a small middle-Asia group involved Pakistan, Malaysia, and Bangladesh. These Africa and Asia groups have links to the US and the EU which are facilitated by the UK-lead core. Grant funding analysis (Fig2 (c,d,e,f)) again revealed a UK-dominated core, but also showed the existence of smaller subgroups with changing membership around Australia and India, with links to the US and the EU again facilitated through the UK-led core.

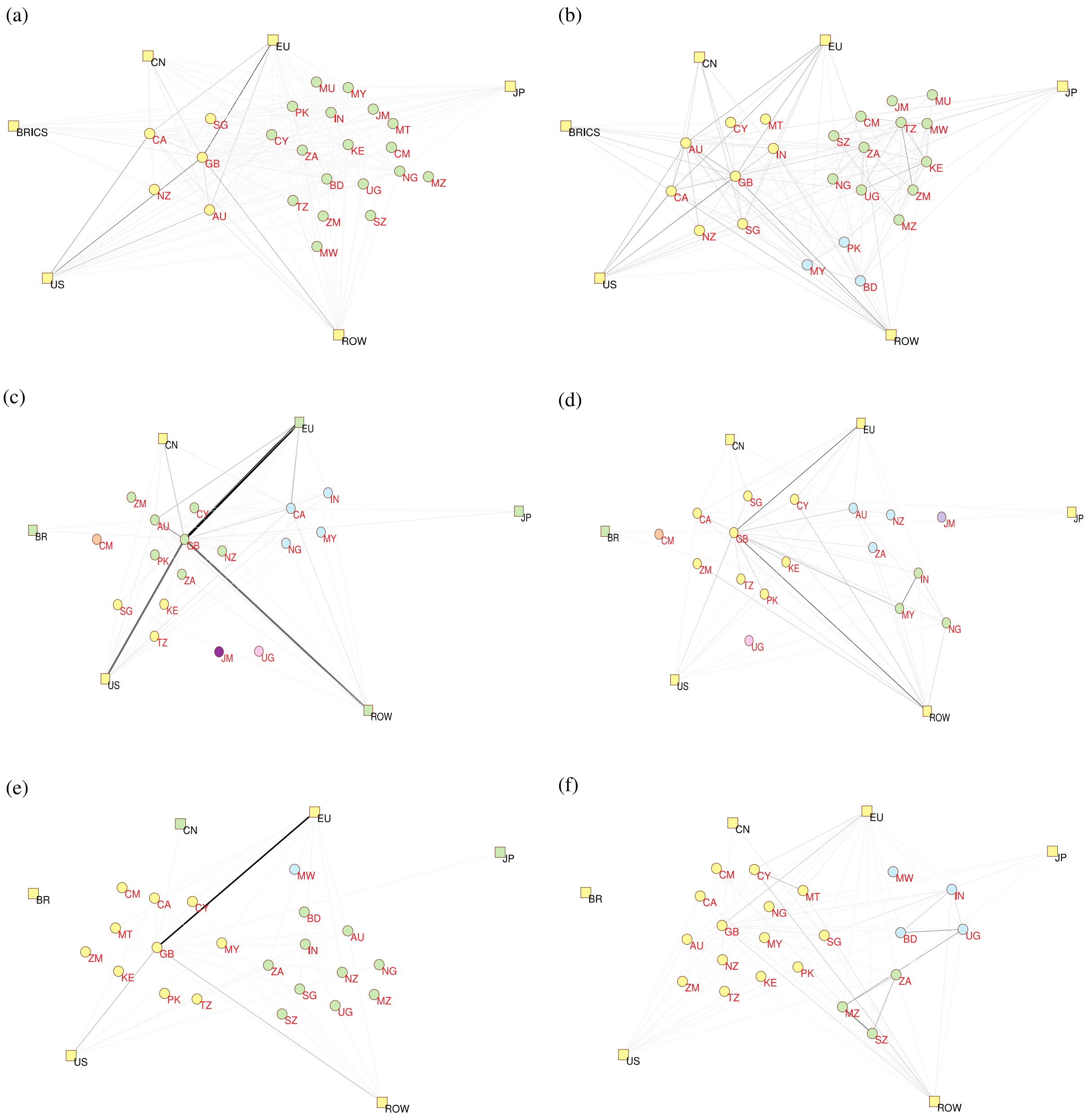

Fig2: Network visualisations of co-authorship and funding co-involvement networks. The positioning of Commonwealth countries (circles with country codes) relative to each other and major countries such as the US, Japan, China, or country groups such as BRICS, the EU and the rest of the world (squares) is shown. Link weights are represented by link colour, with dark colours indicating the strongest connections. Countries are coloured by community membership. Significance of clustering is measured by the modularity m,[25] (a) Co-authorship network for the time period 2016-2023 based on total publication count. At very low significance of modularity (m=0.01), two groupings, one UK-Australia-Canada centric (yellow) and one around the rest of the Commonwealth (green) were identified. (b) Normalised co-authorship network for 2016-2023. At high significance of modularity (m=0.25) three country groupings around the UK, Australia and Canada (yellow), African Commonwealth countries centred around South Africa (green) and a small grouping comprising Pakistan, Bangladesh, and Malaysia (cyan) were identified. (c) Funding co-involvement network for 2016-2020 based on total award count. With low significance (m=0.04) three groupings of

countries, one UK-centric (green), one Canada centric (cyan), and a third comprising Singapore, Kenia and Tanzania and a number of smaller disconnected outlier countries (coloured in black and pink) were identified. (d) Normalised funding co-involvement network for 2016-2020, showing three significant groupings (m=0.15): a UK-centric grouping (yellow), an African grouping around South Africa (cyan), and an India-Malaysia-based grouping (green) (e) Funding co-involvement network for 2021-2023 based on total award count. At very low significance (m=0.02), two country groupings indicated in yellow (UK-centric) and green (African-centric) were identified. (f) Normalised funding co-involvement network for 2021-2023. At high significance (m=0.4), three groupings comprising one large group around the UK, Canada, and Australia (yellow) and two small groups around India (cyan) and around South Africa (green) were identified. Connections between non-Commonwealth countries were not shown.

Discussion

This study describes a comprehensive global analysis of public and philanthropic cancer research funding from 2016 to 2023, covering $51.4 billion from 107955 awards, and the associated downstream research output of 431733 publications. We provided a detailed summary on the position of the Commonwealth countries in cancer research investment and collaboration network.

Treatment modalities like surgery and radiotherapy are integral to cancer care: around 50% of patients require radiotherapy and over 80% of patients require surgery during their disease journey.[34–36] Yet, our findings show the research on these locoregional treatment modalities were severely underfunded throughout 2016-2023. Previous work suggested that it took on average 17 years to translate preclinical knowledge into direct patient benefit[37] with a high failure rate during such translation.[38] This implies that the research investment seen in this study will provide limited direct benefit to cancer patients, highlighting a potential need to redistribute resources to later phases of research to maximise patient benefits.

Global cancer research investment during 2016-2023 is predominately attributed to high-income countries, with the G7 contributing to around 75% of total funding and the US contributing to over 50%. The Commonwealth countries collectively contributed to $8.7 billion (17.0%) of global funding. The vast majority of funding from Commonwealth countries was contributed by high-income countries (e.g. UK, Australia and Canada), but also, invested back to these countries. In contrast, low-income and low-middle-income countries worldwide that carry the majority of cancer burden[1] received a mere $8.4 million (0.1%) research investment and were involved in only 2% of cancer publications globally. Such inequalities restrict the generalisability of cancer knowledge,[39] reinforcing the existing lack of research capacity and thus the heavy cancer burden in LMICs. This highlights an urgent need for international stakeholders to reassess priority setting and funding allocation to impact global cancer control research.

Network analysis of grant-funding collaborations and publications co-authorship allowed a deeper analysis of the Commonwealth's internal collaboration activity and its linkages to the rest of the world. We particularly noted very strong collaboration intensity between a core group of higher-income countries, including the UK, Australia, and Canada, evident in both grant funding and publication networks. Additionally, these countries dominate the links from the Commonwealth to the rest of the world showing strong collaboration with the US and several larger European partner countries. These linkages offer the potential for researchers in the UK, Australia, and Canada to facilitate research collaborations between the US and Europe and lower-income Commonwealth countries.

Network analysis of per publication and per grant output also highlighted the major role of African Commonwealth nations who serve as an important bridge for knowledge transmission from high-income countries to low-income countries in Africa. These linkages can be seen as a backbone network which highlights the potential to grow more intense collaboration among low-income countries, provided there is more access to research funding.[40] When comparing 2016-20 and 2021-23 funding patterns, we also noted a decrease in the breadth of Commonwealth engagement with other countries. It is unclear to us what has been the fundamental drive for this decline, which we leave for future research. The observed decline points to a need for wider engagement to facilitate knowledge transmission in cancer research.

The potential for volatility in future funding for cancer research and global health from the USA means that there may be extended value in other countries working together.[41] Politically-aligned groupings such as the EU, BRICS and the Commonwealth may become increasingly important, with collaborative structures more readily available within these groups. The relative lack of cancer research linkage between Commonwealth countries indicates that more can be done to establish long-term partnerships across high- and low-income countries of the Commonwealth. Thus, where we have described the focal points of these networks such as the UK, and the Africa and Asia groups, these links can be enhanced to improve and widen multi-country research efforts.

There is very little existing activity from LMIC-based funders or researchers. The power imbalance between global north and south is well documented.[42] With cancer mortality being highest in low-income countries,[1] there is that imbalance between burden of disease and lack of regional leadership to develop local research priorities and generate new knowledge supportive of cancer care and case management. Enhancing LMIC research leadership calls for shifting power to local stakeholders by directly funding and empowering LMIC institutions to set agendas, design, and manage research programs.[43] This should be paired with long-term, equitable partnerships that foster mutual learning and coordinated support for sustainable research ecosystems.[43]

This study has several limitations. The investment and bibliometrics analyses cover only public and philanthropic awards, with private sector data not available at the granular level needed for this project. This may result in underestimates, particularly for funding related to radiotherapy, diagnostics, and surgery. The lack of individual award data from Cancer Research UK is unusual among public and charitable funders, and this lower level of transparency also hinders attempts to fully understand the oncology research landscape.[44]

We acknowledge the limitation that not all funded research leads to publications. While scientists tend to publish more positive results, i.e., the file drawer problem, learning what doesn't work is of equal importance, if not more, especially in the context of clinical interventions. Despite this limitation, examining grant and publication altogether would be a good starting point to systematically examine and compare research networks, given the feature of rich and standardized data. Policymakers in health and science should encourage full registration of clinical trials and the publication of all results so that future work might benefit from a more balanced evidence base.

We did not analyse the content of individual papers, thus it is beyond the scope of this manuscript to consider the impact of publications with positive or negative results, any bias towards research reporting increased survivorship, or a focus on a country where this country is not present in the list of author affiliated countries.

Whilst the Dimensions database has collated 7.2 million awards from 700 funders worldwide, some nations will be under-represented, for example, South Korea, Italy and possibly some LMICs—where data has not yet been captured. The Health Research Funders database ranks organisations for their sum spend on research. Our analysis covers 12 of the top 15 ranked funders. Therefore, apart from the pharmaceutical sector, any missing public or charitable data is unlikely to greatly change our findings and conclusions.

The GBD study provides modelled estimates of health data and have been subject to criticism.[45] However GBD figures are widely used across the literature and are regularly updated.

The inclusion, exclusion, and labelling of included awards was carried out with novel automated processes and scrutiny by the co-authors. There will be subjectivity among final decision-making and thus potential for error.

In conclusion, this work highlights inequities in the global funding and publication landscape, with little funding flow to, or research leadership by, lower-income settings. The Commonwealth, being a group of countries covering higher and low-income nations, has the potential to improve collaboration links, and knowledge translation to help reduce these inequities. The novel network methods would allow future analyses to describe continuous temporal assessment of any changes to funding flows and partnerships. There are limited research resources, and we must invest wisely.

Contributors

RA and MGH conceived the study. AD obtained the raw data; all authors had sight of datasets and contributed to the creation of labels and definitions. AD and BZ developed the automated annotation framework and carried out automated award classification. MGH, SMcI, AA, GB, WCH, EC, RIC, AF, EH, ZM, OO, CS, ET contributed to manual award classification. AD carried out statistical analysis. MB and AD carried out network analysis. AD, MB and MGH carried out final collation of results. RA, MGH, SMcI, MB, GB, BZ, and AD met regularly to review data and discuss analysis. AD, MB and MGH wrote the first draft of the manuscript. RA, SMcI, MB, MGH, RIC, CS, EC, GB, ZM, ET contributed to editing and revision. SMcI and MGH accessed and verified the underlying data in the study. All authors have read and approved the final manuscript.

Declaration of interests

SMcI reports speaker honoraria from MSD, Roche, BD, Veracyte and Exact Sciences, advisory boards for Roche, Lilly, Novartis, and MSD, conference travel and support from Roche, Lilly, Novartis, and MSD and institutional research funding from Novartis. EC reports speaker honoraria from AstraZeneca, Lilly, Pfizer, Novartis, Menarini Stemline and Roche; advisory boards for AstraZeneca, Guardant, Lilly, Novartis, Pfizer and Roche; consultancy for Pfizer; conference travel and support from Roche and Novartis; educational support from Daaichi-Sankyo; institutional research funding from AstraZeneca; research support from SECA; research collaboration Proteotype. RIC reports institutional research funding from AstraZeneca; institutional research support from SECA. All other authors declare no competing interests.

Data Sharing

The data source is Dimensions.ai, a privately owned database. They do not permit open sharing of the dataset.

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