Estimates of global chemotherapy demands and corresponding physician workforce requirements for 2018 and 2040: a population-based study

Brooke E Wilson, Susannah Jacob, Mei Ling Yap, Jacques Ferlay, Freddie Bray, Michael B Barton

Summary

Background The incidence of cancer (excluding non-melanomatous skin cancers) is projected to rise from 17·0 million to 26·0 million between 2018 and 2040. A large proportion of these patients would be likely to derive benefit from chemotherapy, but no studies so far have quantified current and projected global chemotherapy demands. We aimed to estimate changes in national, regional, and global demands for first-course chemotherapy and the cancer physician workforce between 2018 and 2040 if all patients were treated according to best-practice evidence-based guidelines.

Methods Data for the incidence of 29 types of cancer in 183 countries in 2018, and projections of incidence in 2040, were obtained from GLOBOCAN 2018. Optimal chemotherapy utilisation from evidence-based guidelines was applied to these incidence data to generate the number of new patients requiring first-course chemotherapy in 2018 and 2040. We then estimated the corresponding cancer physician workforce required to deliver this chemotherapy (on the basis of physicians seeing 150 new patients requiring chemotherapy per year). We did sensitivity analyses to investigate how cancer stage at presentation affected chemotherapy demands. We also did sensitivity analyses to explore changes to workforce requirements if each physician was seeing 100 new patients requiring chemotherapy per year or 300 new patients requiring chemotherapy per year.

Findings Between 2018 and 2040, the number of patients requiring first-course chemotherapy annually will increase from 9·8 million to 15·0 million, a relative increase of 53%. The estimated proportion of patients needing chemotherapy who reside in low-income or middle-income countries was 63% (6 162 240 of 9 782 783) in 2018, and will be 67% (10 071 049 of 14 984 560) in 2040. The most common indications for chemotherapy worldwide in 2040 will be lung cancer (accounting for 2 455 137 [16·4%] of 14 984 560 cases eligible for chemotherapy), breast cancer (1 898 740 [12·7%]), and colorectal cancer (1 678 153 [11·1%]). We estimated that, in 2018, 65 000 cancer physicians were required worldwide to deliver optimal chemotherapy—a figure that we estimate will rise to 100 000 by 2040 (with estimates ranging from from 50 000 to 150 000, depending on workload).

Interpretation Strategic investments in chemotherapy service provision and cancer physicians are needed to meet the projected increased demand for chemotherapy in 2040.

Funding None.

Introduction

According to GLOBOCAN estimates,[1] there were approximately 17·0 million new cancer cases and 9·5 million deaths from cancer worldwide (excluding non-melanomatous skin cancers) in 2018. A growing proportion of these cases are diagnosed in low-income and middle-income countries (LMICs), which will account for an estimated 70% of cancer diagnoses by 2040.[2] The proportion of people with cancer receiving chemotherapy for various tumour types varies substantially worldwide,[3–6] and is lower in many LMICs, at least partly because of issues with the availability of, and access to, cancer care. Insufficient service provision arises from a combination of a scarcity of services for accurate and timely diagnosis, inadequate infrastructure to support the delivery of cancer care, shortfalls in the number of trained personnel, and lack of access to drugs because of cost and supply-chain issues.

As the global medical community continues its commitment to the provision of comprehensive oncology services worldwide,[7] a clear understanding of expected demands for treatment in the coming decades is needed. Evidence-based benchmarking has been used previously to estimate global radiotherapy demands,[8–10] but estimates of global chemotherapy demands have not previously been published. We aimed to estimate chemotherapy use worldwide if first-course chemotherapy were delivered to all patients for whom such treatment is indicated according to evidence-based guidelines. We refer to first-course rather than first-line chemotherapy to reflect the fact that, in LMICs, the best available therapy might not

University of New South Wales, Sydney, NSW, Australia (B E Wilson MSc, S Jacob PhD, M L Yap MBBS, Prof M B Barton MD); **Collaboration for Cancer Outcomes, Research and Evaluation, Ingham Institute for Applied Medical Research, Liverpool, NSW, Australia,** (B E Wilson, S Jacob, M L Yap, Prof M B Barton); **Kinghorn Cancer Centre, St Vincent's Hospital, Darlinghurst, NSW, Australia** (B E Wilson); **Liverpool Cancer Therapy Centre, Liverpool Hospital, Liverpool, NSW, Australia** (M L Yap); **and Macarthur Cancer Centre, Campbelltown Hospital, Campbelltown, NSW, Australia** (M L Yap); **School of Medicine, Western Sydney University, Campbelltown, NSW, Australia** (M L Yap); **School of Public Health, Sydney Medical School, University of Sydney, Sydney, NSW, Australia** (M L Yap); **and Section of Cancer Surveillance, International Agency for Research on Cancer, Lyon, France** (J Ferlay ME, F Bray PhD)

Correspondence to:
Dr Brooke E Wilson, Kinghorn Cancer Centre, St Vincent's Hospital, Darlinghurst, NSW 2000, Australia
brooke.wilson2@svha.org.au

Research in context

Evidence before this study
Studies have shown that the global burden of cancer is increasing, especially in low-income and middle-income countries. However, little is known about the global demands for chemotherapy based on current and projected incidence of cancer by type, or about the workforce required to deliver such chemotherapy. We searched PubMed, Embase, and MEDLINE with the terms "global chemotherapy demands", "global oncology workforce", and "medical oncology workforce" for articles published in English (or with English abstracts) between Jan 1, 2000, and Jan 1, 2019. We found no studies of global chemotherapy demands. Individual country-based studies have estimated the number of cancer physicians needed to meet workload on the basis of clinic visits and other demand indicators, but none have examined workforce requirements globally on the basis of chemotherapy demands.

Added value of this study
To our knowledge, in this study we provide the first estimate of the global demands for chemotherapy on the basis of

evidence-based benchmarking of optimal chemotherapy utilisation. This study provides a reference point for institutions and governments as they develop strategies to tackle the growing cancer burden. It also provides an estimate of the number of cancer physicians required globally to safely deliver chemotherapy to all patients in whom such treatment would either improve survival or provide symptom control.

Implications of all the available evidence
The rising cancer burden and the increasing demands for chemotherapy globally will be major health crises during the next 20 years. The gap between available service provision and demand is substantial, especially in low-income and middle-income countries. Strategic investments to expand capacity for chemotherapy delivery globally are urgently needed. This study aims to trigger needed discussions about the planning and provision of cancer services to meet these needs.

necessarily be the recommended first-line treatment. We also estimated the current and future number of cancer physicians required to safely meet the increasing chemotherapy needs on a national, regional, and global scale.

Methods

Study design and data sources

We did a population-based study to estimate global chemotherapy and physician workforce needs in 2018 and 2040. The global incidences of 29 types of cancer in 183 countries were obtained from GLOBOCAN 2018,[1] which was developed by the International Agency for Research on Cancer. These 29 cancer types were chosen because they account for most cases of cancer worldwide, and each has clear treatment guidelines. GLOBOCAN 2018 includes estimates of the incidence of adult and paediatric malignancies in 2018, and projections of incidence every 5 years from 2020 to 2040.[11] The methods used to estimate incidence in each country have been described previously.[1,11] There were no missing data for this study. Countries were classified into four levels of income according to the World Bank Development Classification for 2018. Low income was defined as an annual gross national income (GNI) of US$995 or less per person, lower middle income as an annual GNI of $996–3895 per person, upper middle income as an annual GNI of $3896–12 055 per person, and high income as an annual GNI of more than $12 055 per person.[12]

We have previously calculated optimal chemotherapy utilisation—defined as the proportion of newly

diagnosed patients with cancer in whom chemotherapy is indicated at least once over the course of their illness—by merging cancer-specific incidence data with indications for chemotherapy based on guidelines generated from published literature about best practice.[13] An indication for chemotherapy was defined as a clinical situation in which treatment with chemotherapy improved overall survival or symptom control. Only indications for a patient's first course of chemotherapy were included in the model. We included targeted therapies in the model, but excluded hormonal therapy and immunotherapy. Patient characteristics and stage data used in the calculation of the optimal chemotherapy utilisation were derived from national population-based data from the USA and Australia. LMICs are likely to have different distributions of cancer stages at presentation compared with the USA and Australia, but accurate data for each country and tumour type were absent. We thus did a sensitivity analysis to explore how changes to stage at diagnosis in LMICs affect chemotherapy demands.

Recognising that not all patients with early malignancies require review by a cancer physician, we estimated requirements for the global cancer physician workforce on the basis of our estimates of the demand for chemotherapy. We defined a cancer physician as a medical professional adequately trained to prescribe and deliver chemotherapy—a definition that includes medical oncologists, haematologists, clinical oncologists, and paediatric physicians managing malignancies. In LMICs, this definition might also include general physicians with sufficient training to prescribe

chemotherapy. The workload per cancer physician varies substantially worldwide. In high-income countries, cancer physicians see on average 175 new patients with cancer per year,[14] whereas in LMICs they see an average of 425 new patients with cancer per year.[14] Furthermore, 58 (39%) of 147 surveyed cancer physicians in LMICs saw more than 500 incident cases per year.[14] In both circumstances, not all incident cases will require chemotherapy. We assumed a full-time equivalent of 150 new patients needing chemotherapy per physician per year, on the basis of estimates[15] that 160–175 new patients per physician per year is a safe workload, and recognising that a small proportion of these patients might not require chemotherapy.

The primary aim of our study was to estimate global chemotherapy demands in 2018 and 2040. Our secondary aims were to investigate the effect of stage distribution at presentation on global chemotherapy demands, and to estimate the required cancer physician workforce based on chemotherapy demands.

Statistical analysis

To estimate chemotherapy demands nationally, regionally, and globally, we multiplied the number of new cancer cases (derived from GLOBOCAN 2018 data) by the calculated optimal chemotherapy utilisation to generate the number of new cases of cancer requiring chemotherapy for the 29 cancer types. Although calculations were done for 2018 and each 5-year timepoint between 2020 and 2040, only the first and last estimates are presented because changes were approximately linear over time. We then estimated national chemotherapy utilisations on the basis of the distribution of cancer subtypes in each country. We also calculated the absolute difference and the percentage change in chemotherapy demand between 2018 and 2014. Finally, we analysed chemotherapy demands stratified by income level, based on World Bank Income groupings (low income, lower middle income, upper middle income, and high income). We assessed differences in chemotherapy utilisation by income group with the χ^2 test.

We did a sensitivity analysis to examine the effect of stage distribution at diagnosis by country on global chemotherapy demands. We generated three stage distributions for each of the 29 cancer types: a high-income (optimal) stage distribution, based on US and Australian population data that represented the expected stage distribution in the setting of optimal diagnostic and screening services; an intermediate stage distribution assuming that 30% of those with stage I and II disease presented instead with locally advanced or metastatic disease (with the additional advanced cases divided equally between stage III and IV disease); and an advanced stage distribution assuming that all patients present with locally advanced or metastatic disease (divided equally between stages III

and IV disease; appendix pp 7–9). On the basis of these three stage distributions, we generated three sets of chemotherapy utilisation estimates (optimal, intermediate, advanced) for the 29 cancer types (appendix p 9). These chemotherapy utilisation estimates were then applied to five scenarios in which the stage of presentation varied by the income level of the country. In the first scenario, we assumed that all countries had optimal stage distributions. In the second scenario, we assumed that LMICs had intermediate stage distributions, whereas high-income countries had optimal stage distributions. In the third scenario, the intermediate scenario, we assumed that 30% of those with stage I and II disease in lower-middle-income and upper-middle-income countries would present with locally advanced or metastatic disease, all patients in low-income countries would present with locally advanced or metastatic disease, and stage distribution would remain unchanged in high-income countries. In the fourth scenario, we assumed that low-income and lower-middle-income countries had advanced disease stage distributions, upper-middle-income countries had intermediate stage distributions, and high-income countries had optimal stage distributions. In the fifth scenario, the worst-case scenario, we assumed that all patients in low-income, lower-middle-income, and upper-middle-income countries presented with locally advanced or metastatic disease, whereas high-income countries had optimal stage distributions. We then calculated the change in the proportion of people who would benefit from chemotherapy over time (ie, from 2018 to 2040) and estimated chemotherapy utilisation according to these five scenarios.

We estimated workforce needs to meet the chemotherapy demands by dividing the number of patients requiring chemotherapy by 150 to generate the number of cancer physicians required to deliver this care. We did sensitivity analyses to explore changes to workforce requirements if each physician was seeing 100 new patients requiring chemotherapy per year or 300 new patients requiring chemotherapy per year. Workloads in excess of 300 new chemotherapy cases per year exceed recommendations about safe working standards in the setting of optimal care provision.[15]

Role of the funding source

There was no funding source for this study. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

In 2018, optimal chemotherapy utilisation globally was 57·7%. There were an estimated 17·0 million new cases of cancer, excluding non-melanomatous skin cancers,[1] and we estimated that 9·8 million people would benefit from chemotherapy at some point during their illness

	Optimal chemotherapy utilisation (%)	Incident cases, 2018 (n)	Incident cases, 2040 (n)	Chemotherapy utilisation, 2018 (n)	Chemotherapy utilisation, 2040 (n)	Proportion of global chemotherapy demand, 2018	Proportion of global chemotherapy demand, 2040	Absolute increase in chemotherapy utilisation (n)	% change
Lip or oral cavity	22·9%	354 864	554 361	81 264	126 949	0·8%	0·8%	45 685	56%
Salivary gland	38·1%	52 799	81 604	20 116	31 091	0·2%	0·2%	10 975	55%
Oropharynx	69·7%	92 887	133 508	64 742	93 055	0·7%	0·6%	28 313	44%
Nasopharynx	72·7%	129 079	173 307	93 840	125 994	1·0%	0·8%	32 154	34%
Hypopharynx	73·9%	80 608	128 868	59 569	95 233	0·6%	0·6%	35 664	60%
Oesophagus	72·5%	572 034	941 980	414 725	682 936	4·2%	4·5%	268 211	65%
Stomach	83·0%	1 033 701	1 710 324	857 972	1 419 569	8·8%	9·5%	561 597	65%
Colon	55·3%	1 096 601	1 776 687	606 420	982 508	6·2%	6·5%	376 088	62%
Rectum	64·2%	704 376	1 083 559	452 209	695 645	4·6%	4·6%	243 436	54%
Liver	52·0%	841 080	1 321 679	437 362	687 273	4·5%	4·6%	249 911	57%
Gallbladder	79·8%	219 420	388 948	175 097	310 381	1·8%	2·1%	135 284	77%
Pancreas	35·5%	458 918	758 039	162 916	269 104	1·7%	1·8%	106 188	65%
Larynx	43·1%	177 422	281 723	76 469	121 423	0·8%	0·8%	44 954	59%
Lung	73·2%	2 093 876	3 354 012	1 532 717	2 455 137	15·7%	16·4%	922 420	60%
Melanoma	18·6%	287 723	387 914	53 516	72 152	0·5%	0·5%	18 636	35%
Breast	67·0%	2 088 849	2 833 941	1 399 529	1 898 740	14·3%	12·7%	499 211	36%
Cervix	51·4%	569 847	841 899	292 901	432 736	3·0%	2·9%	139 835	48%
Corpus	20·8%	382 069	500 020	79 470	104 004	0·8%	0·7%	24 534	31%
Ovary	84·2%	295 414	412 325	248 739	347 178	2·5%	2·3%	98 439	40%
Prostate	15·4%	1 276 106	2 092 030	196 520	322 173	2·0%	2·2%	125 653	64%
Testis	70·4%	71 105	77 285	50 058	54 409	0·5%	0·4%	4351	9%
Kidney	32·7%	403 262	576 531	131 867	188 526	1·3%	1·3%	56 659	43%
Bladder	72·8%	549 393	909 719	399 958	662 275	4·1%	4·4%	262 317	66%
Brain or CNS	72·2%	296 851	407 225	214 326	294 016	2·2%	2·0%	79 690	37%
Thyroid	13·2%	567 233	665 932	74 875	87 903	0·8%	0·6%	13 028	17%
Hodgkin lymphoma	95·0%	79 990	104 251	75 990	99 038	0·8%	0·7%	23 048	30%
Non-Hodgkin lymphoma	84·0%	509 590	772 968	428 056	649 293	4·4%	4·3%	221 237	52%
Multiple myeloma	93·8%	159 985	254 476	150 066	238 699	1·5%	1·6%	88 633	59%
Leukaemia	85·6%	437 033	612 126	374 100	523 980	3·8%	3·5%	149 880	40%
Other	50·0%	1 154 787	1 826 280	577 394	913 140	5·9%	6·1%	335 746	58%
Total	..	17 036 902	25 963 521	9 782 783	14 984 560	100%	100%	5 201 777	53%

Table 1: Optimal chemotherapy utilisation worldwide in 2018 and 2040, by cancer type

on the basis of existing treatment guidelines. In 2040, the number of new cases of cancer is projected to rise to 26 million globally,[1] and we estimated that 15·0 million people will require chemotherapy— an absolute increase of 5·2 million people requiring chemotherapy, or a 53% increase (table 1). The most common indications for chemotherapy in 2040 will be lung cancer (accounting for 2 455 137 [16·4%] of 14 984 560 cases eligible for chemotherapy), breast cancer (1 898 740 [12·7%] cases), and colorectal cancer (1 678 153 [11·1%] cases; table 1). We estimated that, between 2018 and 2040, the greatest absolute increases in the number of patients needing chemotherapy will occur for the same three malignancies (around an additional 922 000 cases of lung cancer, 620 000 cases of

colorectal cancer, and 499 000 cases of breast cancer requiring chemotherapy annually; table 1). Between 2018 and 2040, the requirement for chemotherapy is expected to increase by the greatest relative amount for gallbladder cancer (by 77%) and for bladder cancer (by 66%; table 1).

Income-level data were available for 16 902 812 (99·2%) of 17 036 902 incident cases in 2018, and 25 561 010 (98·4%) of 25 963 521 incident cases in 2040. The largest proportion of patients requiring chemotherapy in 2040 is predicted to reside in upper-middle-income countries (43·2%; table 2; figure 1). 75% of the additional cases requiring chemotherapy in 2040 will occur in LMICs (table 2). We noted no association between income level and optimal

	New cases, 2018 (n=17 036 902)	New cases, 2040 (n=25 963 521)	Chemotherapy utilisation, 2018 (n=9 782 783)	Chemotherapy utilisation, 2040 (n=14 984 560)	Absolute increase in chemotherapy utilisation (n=5 201 777)	Chemotherapy utilisation, 2040 (%)	Workforce, 2018 (n=65 219)	Workforce, 2040 (n=99 897)
Low-income countries (n=34)	541 991 (3·2%)	1 120 972 (4·3%)	312 452 (3·2%)	641 585 (4·3%)	329 133 (6·3%)	57%	2083 (3·2%)	4277 (4·3%)
Lower-middle-income countries (n=44)	2 978 779 (17·5%)	5 078 804 (19·6%)	1 744 085 (17·8%)	2 963 540 (19·8%)	1 219 454 (23·4%)	58%	11 627 (17·8%)	19 757 (19·8%)
Upper-middle-income countries (n=48)	6 897 388 (40·5%)	10 810 113 (41·6%)	4 105 703 (42·0%)	6 465 924 (43·2%)	2 360 221 (45·4%)	60%	27 371 (42·0%)	43 106 (43·2%)
High-income countries (n=54)	6 484 654 (38·1%)	8 551 121 (32·9%)	3 544 728 (36·2%)	4 698 696 (31·4%)	1 153 968 (22·2%)	55%	23 632 (36·2%)	31 325 (31·4%)
Unclassified*	134 090 (0·8%)	402 511 (1·6%)	75 814 (0·8%)	214 815 (1·4%)	139 001 (2·7%)	53%	505 (0·8%)	1432 (1·4%)

Data are n (%), unless otherwise indicated. *Includes countries for which no income class is assigned by the World Bank, and where no country level data were available from GLOBOCAN; these figures were calculated as the difference between the world total and the sum of the income level data presented.

Table 2: Estimates of absolute increases in chemotherapy use and cancer physician workforce between 2018 and 2040, by income level

chemotherapy utilisation (p=0·91). In 2040, optimal chemotherapy utilisation was projected to be highest in upper-middle-income countries (60%) and lowest in high-income countries (55%; table 2), assuming a high-income stage distribution in all countries. We estimated optimal chemotherapy utilisation of less than 50% in seven countries and of 60% or higher in 36 countries (figure 2).

On a regional level, eastern Asia will have the highest chemotherapy utilisation (62%) in 2040, followed by northern Africa (60%; table 3). By contrast, Australia and New Zealand, Melanesia, Polynesia, and Central America will have the lowest chemotherapy utilisation (table 3). Of the 15·0 million people requiring chemotherapy in 2040, 35·0% will reside in eastern Asia, 11·5% in south central Asia, 9·5% in northern America, 6·5% in southeastern Asia, 6·2% in South America, and 5·4% in western Europe (table 3).

Of the additional 5·2 million people requiring chemotherapy in 2040 compared with 2018, 35·3% will reside in eastern Asia, 13·8% in south central Asia, and 7·9% in northern America (table 3). However, the greatest proportional growths in chemotherapy needs from 2018 to 2040 were projected to occur in eastern Africa (a 115% increase), middle Africa (114%), western Africa (100%), and western Asia (99%; table 3). The smallest proportional growth between 2018 and 2040 was projected in eastern Europe (12%; table 3).

Country-level calculations for optimal chemotherapy utilisation varied substantially, from 47% in Barbados to 65% in Bhutan (figure 2; appendix pp 1–6). The number of new patients needing chemotherapy in 2040 was projected to be fewer than 5000 in 47 countries, and more than 75 000 in 31 countries (figure 3). China has the highest chemotherapy demand in 2040, with 4·2 million new patients meeting criteria for treatment— corresponding to 27·8% of global chemotherapy needs.

In 2018, 65 219 cancer physicians were required to
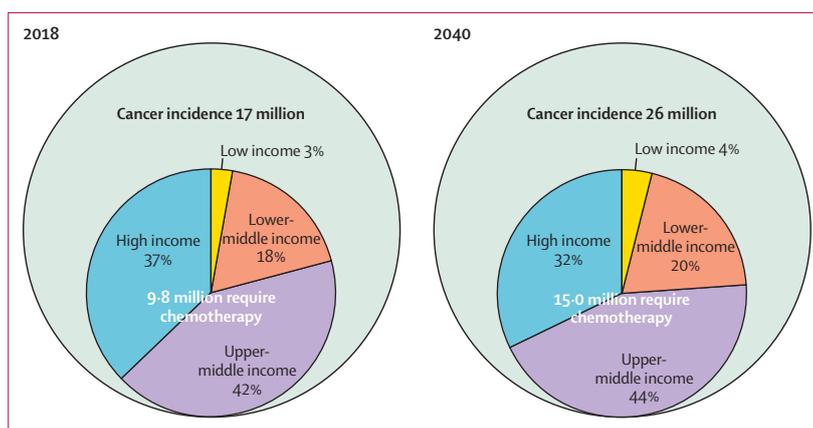
Figure 1: Growth in cancer incidence and chemotherapy demand between 2018 and 2040 stratified by income level
The pie charts include data only for countries that have been assigned an income class by the World Bank and for which country-level GLOBOCAN estimates are available. Therefore the numbers presented in the pie charts differ slightly from those in table 2.

deliver chemotherapy to all cancer patients worldwide (if each physician saw 150 new patients requiring chemotherapy, and if all patients in whom chemotherapy was indicated received treatment). The required number of physicians ranged from 32 609 (if each physician saw 300 new patients requiring chemotherapy) to 97 828 (if each physician saw 100 new patients requiring chemotherapy) depending on estimated workload. In 2040, we estimated that 99 897 cancer physicians will be required; estimates range from 49 949 to 149 846, depending on workload (table 4). Of the total physicians needed in 2040, 31·4% will be required in high-income countries, whereas 67·2% will be needed in LMICs (table 2).

In 2040, based on a full-time equivalent workload of 150 new chemotherapy patients per year, the greatest number of cancer physicians will be required in eastern Asia (35 000, corresponding to 35·0% of the global
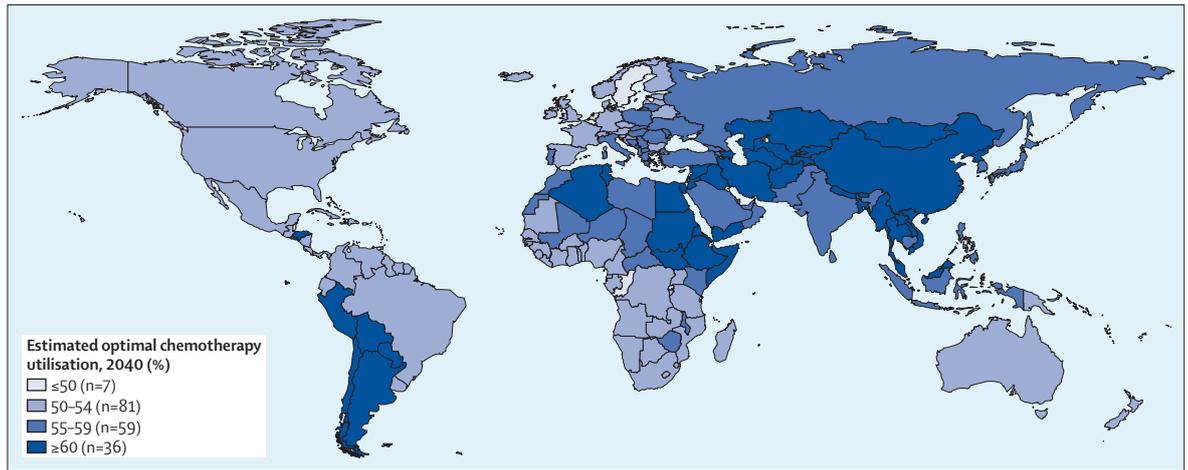
***Figure 2:* Estimated optimal chemotherapy utilisation in 2040, by country**
Estimates are the proportion of patients with a new indication for first-course chemotherapy.

	Incident cases, 2018 (n)	Incident cases, 2040 (n)	Chemotherapy utilisation, 2018 (n)	Chemotherapy utilisation, 2040 (n)	Absolute increase in chemotherapy utilisation (n)	% change	Chemotherapy utilisation, 2040 (%)	Workforce, 2018 (n)	Workforce, 2040 (n)
Eastern Africa	324 872	700 049	184 289	395 519	211 230	115%	56%	1229	2637
Middle Africa	94 004	202 413	50 932	108 896	57 964	114%	54%	340	726
Northern Africa	279 108	521 164	169 293	313 014	143 721	85%	60%	1129	2087
Southern Africa	108 899	181 543	58 580	97 009	38 429	66%	53%	391	647
Western Africa	224 163	450 802	123 565	247 051	123 486	100%	55%	824	1647
Caribbean	106 577	164 773	56 437	86 656	30 219	54%	53%	376	578
Central America	245 529	463 880	128 435	238 128	109 693	85%	51%	856	1588
South America	992 055	1 732 004	533 228	922 452	389 224	73%	53%	3555	6150
Northern America	1 896 063	2 625 967	1 012 476	1 422 480	410 004	40%	54%	6750	9483
Eastern Asia	5 587 812	8 506 545	3 413 280	5 248 103	1 834 823	54%	62%	22 755	34 987
Southeastern Asia	975 838	1 649 792	582 901	980 646	397 745	68%	59%	3886	6538
South central Asia	1 719 178	2 941 530	1 014 202	1 730 310	716 108	71%	59%	6761	11 535
Western Asia	390 616	784 183	227 992	454 820	226 828	99%	58%	1520	3032
Eastern Europe	1 202 972	1 348 580	670 724	750 186	79 462	12%	56%	4471	5001
Northern Europe	623 404	821 562	330 939	436 904	105 965	32%	53%	2206	2913
Southern Europe	872 216	1 083 551	482 497	599 579	117 082	24%	55%	3217	3997
Western Europe	1 212 725	1 506 542	651 215	810 084	158 869	24%	54%	4341	5401
Australia and New Zealand	163 754	247 520	82 788	126 409	43 621	53%	51%	552	843
Melanesia	14 594	26 903	7665	14 060	6395	83%	52%	51	94
Polynesia	1539	2537	803	1322	519	65%	52%	5	9
Unclassified*	984	1681	542	932	390	72%	55%	4	6
World	17 036 902	25 963 521	9 782 783	14 984 560	5 201 777	53%	58%	65 219	99 897

Because of rounding during calculations, the numbers in the World row might not equal the sum of the indivudal columns. *Unclassified is the difference between the world estimate and the sum of the regional estimates, and accounts in part for countries for which no country-specific estimates were available.

***Table 3:* Regional and global estimates of optimal chemotherapy utilisation and cancer physician workforce in 2018 and 2040, by region**
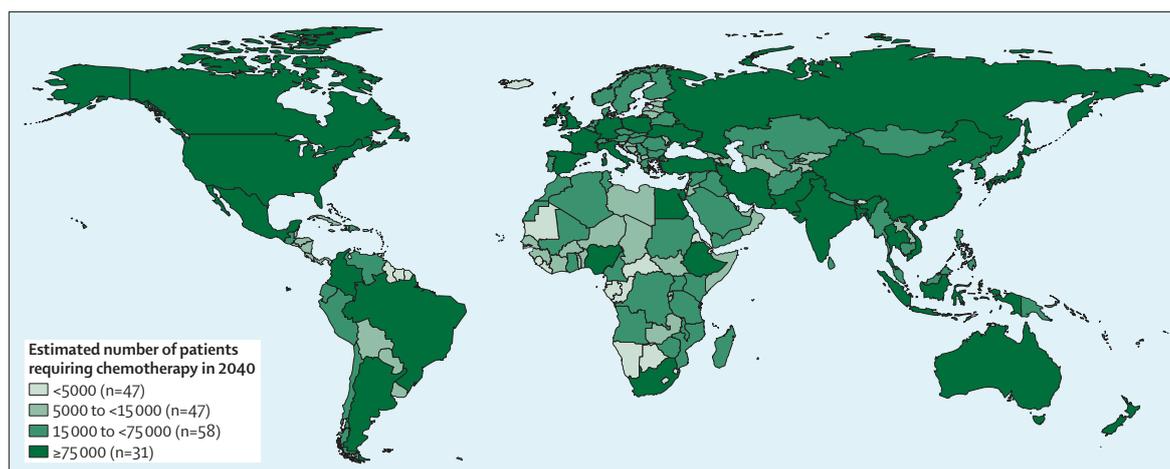
Figure 3: Estimated number of new patients requiring chemotherapy in 2040, by country

workforce), followed by south central Asia (11·5% of the global workforce) and northern America (9·5% of the global workforce; table 3). At a country level, China will require the greatest number of cancer physicians in 2040 (27739), followed by the USA (8403) and India (7352; appendix pp 1–6).

In our sensitivty analysis, we found that changes to stage distribution at diagnosis could result in a 7–24% increase in chemotherapy demand, depending on the scenario (figure 4A; appendix p 10). In the fifth (worst-case) scenario, we estimated that the number of people who would benefit from chemotherapy in 2040 would increase by 24·5% compared with our baseline estimate (figure 4; appendix p 10). In this scenario, chemotherapy utilisation globally would increase to 71·0% in 2018 and to 71·9% in 2040. In the third scenario, the intermediate scenario, there would be a 9·1% increase in the number of people who would benefit from chemotherapy in 2040 compared with the first scenario calculation for 2040 (figure 4B; appendix p 10). Chemotherapy utilisation globally would increase to 62·2% in 2018, and to 63·0% in 2040 (appendix p 10), with a proportional increase in the workforce requirements.

Discussion

To our knowledge, this study is the first to provide an estimate of current and future chemotherapy demands and workforce requirements—both worldwide and by region and country—on the basis of evidence-based guidelines. Between 2018 and 2040, we estimated that the number of people requiring chemotherapy will rise by 53% if evidence-based guidelines are fully adhered to. Of the additional 5·2 million people whom we estimated would benefit from chemotherapy in 2040 compared with 2018, 75% will be in LMICs. We also estimated that, by 2040, almost 100 000 cancer physicians will be required to deliver optimal chemotherapy services globally.

	Cancer physician workforce estimates by workload, 2018			Cancer physician workforce estimates by workload, 2040		
	Low	Middle	High	Low	Middle	High
Eastern Africa	1843	1229	614	3955	2637	1318
Middle Africa	509	340	170	1089	726	363
Northern Africa	1693	1129	564	3130	2087	1043
Southern Africa	586	391	195	970	647	323
Western Africa	1236	824	412	2471	1647	824
Caribbean	564	376	188	867	578	289
Central America	1284	856	428	2381	1588	794
South America	5332	3555	1777	9225	6150	3075
Northern America	10 125	6750	3375	14 225	9483	4742
Eastern Asia	34 133	22 755	11 378	52 481	34 987	17 494
Southeastern Asia	5829	3886	1943	9806	6538	3269
South central Asia	10 142	6761	3381	17 303	11 535	5768
Western Asia	2280	1520	760	4548	3032	1516
Eastern Europe	6707	4471	2236	7502	5001	2501
Northern Europe	3309	2206	1103	4369	2913	1456
Southern Europe	4825	3217	1608	5996	3997	1999
Western Europe	6512	4341	2171	8101	5401	2700
Australia and New Zealand	828	552	276	1264	843	421
Melanesia	77	51	26	141	94	47
Polynesia	8	5	3	13	9	4
Unclassified*	5	4	2	9	6	3
World	97 828	65 219	32 609	149 846	99 897	49 949

Estimates are based on estimated workloads. Low is the cancer physician workforce estimate if each physician were to see 100 new patients needing chemotherapy each year. Medium is the cancer physician workforce estimate if each physician were to see 150 new patients needing chemotherapy each year. High is the cancer physician workforce estimate if each physician were to see 300 new patients needing chemotherapy each year. Because of rounding during calculations, the numbers in the World row might not equal the sum of the individual columns. *Unclassified is the difference between the world estimate and the sum of the regional estimates, and accounts in part for workforce needs in countries for which no country-specific estimates were available.

Table 4: Sensitivity analysis for optimal cancer physician workforce estimates, by region
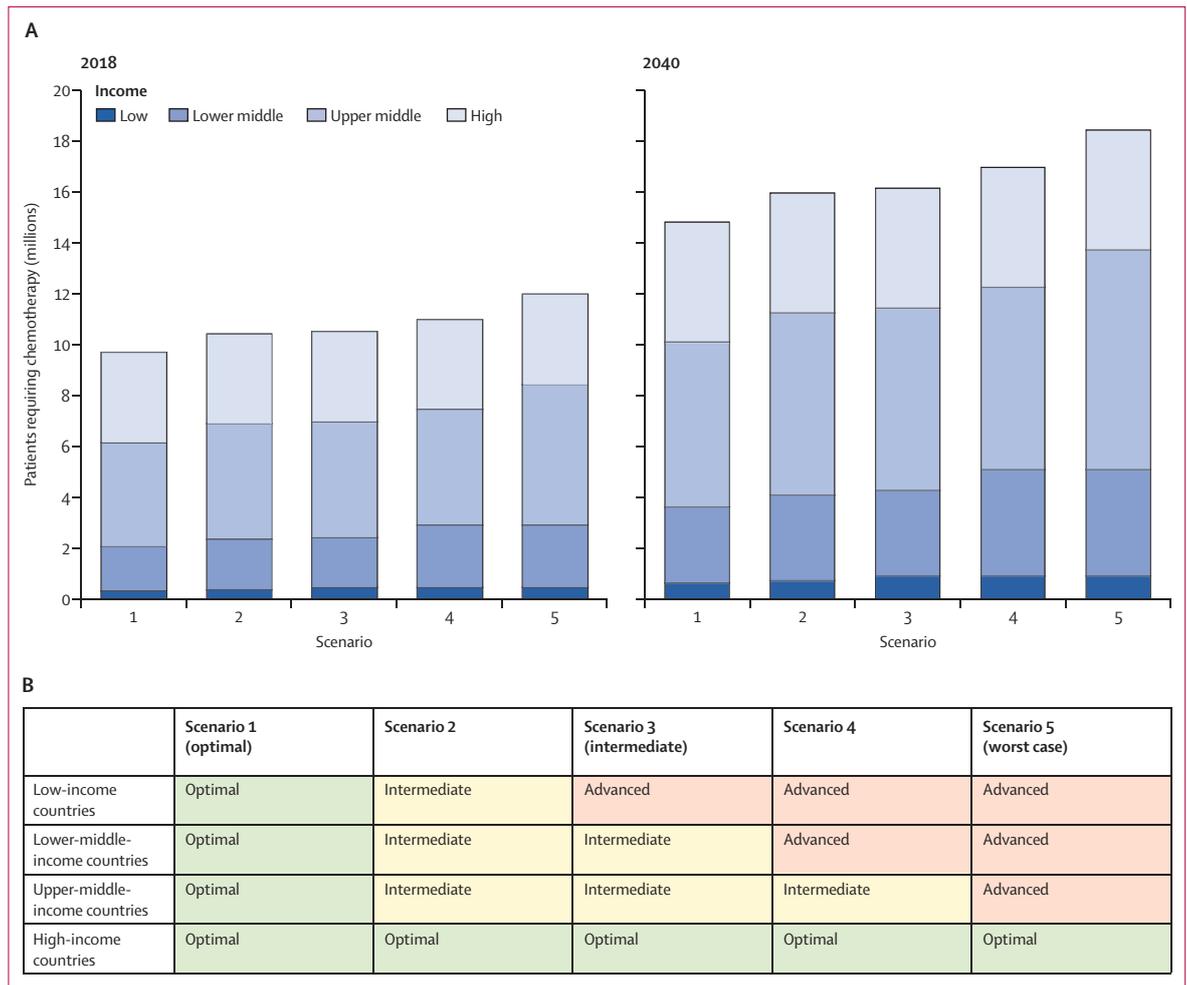
Figure 4: Etimated changes to the number of patients requiring chemotherapy in 2018 and 2040 in sensitivty analyses based on cancer stage at presentation (A) and representative scenarios of distribution of cancer stage at presentation (B), by income group

Optimal stage distribution was based on US and Australian population data, and was the expected stage distribution if optimal screening and diagnostic services were available. For the intermediate stage distribution, we assumed that 30% of people with stage I and II disease presented instead with locally advanced or metastatic disease (with the additional advanced cases divided equally between stage III and IV disease). In the advanced stage distribution, we assumed that all patients presented with locally advanced or metastatic disease (divided equally between stages III and IV disease).

We calculated an optimal chemotherapy utilisation globally of 57·7% in 2040, which varied substantially by region. National income level and optimal chemotherapy utilisation were not significantly associated, but chemotherapy utilisation varied geographically, reflecting regional differences in cancer subtypes. The calculated chemotherapy utilisation provides an estimate of demand, but actual utilisation is often far lower than expected, even in high-income countries.[16] In the Netherlands, estimated adjuvant chemotherapy utilisation for stage III colorectal cancer was 58% in 2006, compared with our previously estimated optimal rate of 89%.[5,17] A population cohort study[6] in the USA showed that, in patients with stage II and III rectal cancer and stage III colon cancer, chemotherapy utilisation varied by patient demographics and hospital

characteristics, from 88% in those aged younger than 55 years to 11% for those older than 85 years. Actual chemotherapy utilisation might be lower than the optimal calculated percentages for various reasons, including patients' or physicians' preferences for treatment, treatment expenses, patient fitness, cultural acceptance of chemotherapy, lack of access to cancer services, and regional variations in practice.

The gap between actual and optimal chemotherapy utilisation in LMICs is even greater. A study from China[4] showed that only 49 (20%) of 250 patients with stage IIIA lung cancer, and 62 (31%) of 202 patients with stage IIIB lung cancer, received recommended combinations of chemotherapy and radiotherapy. In a Ugandan study[3] of breast cancer, of the 247 patients in whom chemotherapy was clearly indicated, only 87

(35%) completed the recommended treatment. In LMICs, the cost of chemotherapy drugs is a substantial barrier to delivery and, in the absence of public health insurance, many patients are unable to pay. Other major barriers to chemotherapy administration include a scarcity of chemotherapy drugs, infrastructure for drug delivery, supportive pathology and radiology services, and trained personnel. This restricted access to care directly affects survival. In one study, overall 5-year survival in patients with breast cancer was 56% in Uganda compared with 82–88% in North America.[3] Optimal cancer outcomes will only be achieved by combining chemotherapy with surgical and radiotherapy services, and the many challenges associated with providing these services in LMICs have been detailed previously.[8,18] However, economic growth across all countries is likely to increase the demand for, and feasibility of, delivering chemotherapy, and plans to increase treatment capabilities globally are urgently needed. Opportunities to reduce costs and expand capacity should be sought via partnerships between patient groups, governments, pharmaceutical companies, and health services. As has been previously suggested,[19] a strategy similar to the response to the AIDS epidemic, which is an example of what can be achieved with innovative treatment models and productive partnerships between public and private sectors, should be adopted.

In the most extensive survey[20] on the global oncology workforce so far, estimates were available for only 93 countries, and there was substantial range in clinical roles. The greatest shortfalls in the workforce were in Africa, where many countries had no formally qualified cancer physicians despite growing needs. With 100 000 cancer physicians estimated to be required worldwide to deliver chemotherapy in 2040, and a third of this workforce required in eastern Asia alone, the workforce needs are substantial and inequitable in terms of region and level of development. In China, roughly 28 000 physicians will be needed to deliver chemotherapy by 2040. Data from 2014 suggested that the oncology workforce in China comprised approximately 25 600 people,[4] suggesting that there is no unmet workforce need. However, this workforce estimate might encompass professionals with varying levels of training and experience in delivery of chemotherapy, because no national oncology specialty training programmes exist. Finally, many small countries require only one or two cancer physicians within a multidisciplinary team to delivery chemotherapy. In these settings, training clinical oncologists with the capacity to deliver both chemotherapy and radiotherapy is an appealing option.

In the USA, we estimated a requirement of 8403 cancer physicians in 2040. According to the American Society of Clinical Oncology's 2016 report[21] on workforce, there are currently more than 12 000 physicians handling approximately 1·7 million new cases of cancer per year, equating to 143 new cases per full-time physician. By contrast, a shortage of medical oncologists has been projected by 2020–25 in some studies.[22,23] These differences hinge on definitions of full-time-equivalent workload and the demand indicator on which workforce projections are based, and show disparities in workforce practices even in high-income countries. Our estimates, based on a full-time equivalent of 150 new patients requiring chemotherapy per year per physician, should be viewed as conservative.

Our study has several limitations. We do not address whether the projected chemotherapy interventions are cost-effective. The costs of chemotherapy drugs can vary substantially across the world, depending partly on the buying power of the nation and negotiated pricing with drug companies.[24] Furthermore, what is judged to be cost-effective by one country might not be deemed cost-effective by others with constrained health budgets. There is a paucity of data on the cost-effectiveness of chemotherapy in LMICs. The authors of a systematic review[25] identified only 15 articles about the cost-effectiveness of interventions for breast, colon, liver, oral, and paediatric cancers in LMICs, and none of these articles addressed chemotherapy. Nonetheless, WHO has identified several situations in which the combination of chemotherapy with surgery or radiotherapy, or both, might be cost-effective, such as adjuvant therapy for breast and colon cancer,[26] but further studies are clearly needed. Furthermore, we did not consider social acceptance of chemotherapy or resource availability in our sensitivity analyses, because the objective of this study was to estimate demand based on global delivery of best practice derived from scientific evidence.

Another limitation is that we applied Australian and US Surveillance, Epidemiology, and End Results Program stage data across all countries to estimate chemotherapy demands. We have previously shown[27] that these data approximate stage data for many high-income countries, including European countries. Unfortunately, information about distribution of stages in LMICs is very scarce. Cancer notification for most LMIC registries is triggered by pathological diagnosis, often without accompanying clinical information to infer stage. The few data that are available suggest that patients in LMICs present with more advanced disease than those in high-income countries.[28] For example, in the USA, approximately 17·4% of patients present with locally advanced or metastatic breast cancer, compared with 50% of patients in Egypt and 50–70% in India (with regional variability).[29–31] In a systematic review[32] that included 83 studies from sub-Saharan Africa with staging data for 24 213 patients, the median proportion presenting with locally advanced or metastatic disease was 74·7%. Because patients with

more advanced disease are more likely to have an indication for chemotherapy, our results could underestimate chemotherapy requirements for LMICs. Our sensitivity analysis showed that changes to distributions of cancer stage at diagnosis could increase global chemotherapy demands by 7–24%. Population-based data for cancer stage distributions at diagnosis in LMICs are urgently needed to improve predictions of global chemotherapy demands. Efforts are underway to address the paucity of data through use of Essential TNM, a simplified staging system developed for cancer registries when full TNM data are absent.[33]

Based on the methods used in this study, the main factors affecting the increase in chemotherapy demands were population growth and projected changes in the distributions of cancer types by country. Patient factors such as age, performance status, and stage at diagnosis might change by 2040, but these changes cannot be accounted for in the model. Our model also assumes that patient characteristics are consistent across all countries and are similar to the Australian and US data on which our chemotherapy utilisation estimates were based. Within each cancer type, histology and topography could vary between countries and genetically diverse populations, but we assumed that they were constant globally because of the absence of reliable country-level data for these potential differences. Therefore, we also assumed that, for each cancer type, indications for chemotherapy are homogeneous worldwide. Another assumption in our study was that chemotherapy indications will not change with time, even though indications for chemotherapy have increased for many cancer types.[34] These increases are partly because of expanded indications for existing therapies and partly because of the development of novel targeted therapies, such as monoclonal antibodies and tyrosine-kinase inhibitors. Furthermore, immunotherapy indications are changing rapidly, which could affect chemotherapy indications. However, these drugs are available to only a fraction of people in whom they might be indicated and would not substantially affect global chemotherapy demands. Our model accounts only for first-course chemotherapy and does not include demands for subsequent lines of treatment. High-quality data for the use of second-course and third-course chemotherapy globally are scarce. Moreover, subsequent courses of therapy tend to offer diminishing returns in both response and survival, and are often associated with increasing costs; nonetheless the exclusion of these therapies is an important limitation that warrants future research. Finally, because chemotherapy indications in guidelines are based on the availability of surgery and radiotherapy, our analysis assumed that these services were also optimally available.

Our estimates of chemotherapy utilisation and work-force requirements rely on the validity of the GLOBOCAN 2018 data for cancer incidence. The accuracy of GLOBOCAN estimates depends partly on the extent and quality of locally available data, as previously described.[11] Only 24% of the world's population is covered by cancer registration systems, and equivalent cancer mortality data are recorded for approximately 43% of the global population.[2] Nonetheless, the GLOBOCAN data remain the most robust estimates of cancer incidence worldwide. Efforts to expand and improve cancer registry data in LMICs through the Global Initiative for Cancer Registry Development (led by the International Agency for Research on Cancer) have the dual aim of supporting local cancer action and ensuring more robust national and global cancer estimates.

Our estimates assume that delivery of cancer care to the level of service provision in high-income countries is a feasible endpoint globally. This goal will be challenging to meet in the near future, but we argue that guidelines from high-income countries represent the highest standard of care available to patients. Therefore, their application to LMICs provides an estimate of global demand if optimal levels of care were applied equitably to all people of the world, without discrimination by country of origin, socioeconomic class, or resource availability. This level of care should be aimed for in the coming decades. Subsequent research should focus on estimation of demands for treatment and workforce requirements based on resource-appropriate prioritisation of treatment options. These estimates should be modelled relative to existing resource-stratified guidelines[35–38] for cancer care in LMICs, with service provision delineated for basic, limited, enhanced, and maximum availability of resources.

The lack of trained personnel is a substantial barrier to expansion of cancer services in many countries. Estimates of the nursing workforce required to safely delivery chemotherapy globally is beyond the scope of this Article, but warrant further research and should form part of all countries' national cancer-management strategies. Cancer physicians require up to a decade of dedicated training, and therefore rapid expansion of service capacity is not possible. Initiatives such as Partners In Health in Malawi, Haiti, and Rwanda have shown that chemotherapy can be safely delivered by local physicians and nurses if provided with adequate remote support from specialist centres.[19] Such a strategy could serve as an intermediate solution to allow for rapid expansion of service delivery while local capacity is developing and could also allow for more conservative estimates of cancer physician requirements in LMICs. However, even these types of partnerships require a basic amount of infrastructure, accurate pathology services, reliable sourcing of drugs, reliable communication networks, and general physicians, which might not be available in LMICs. As many

LMICs work towards developing national cancer-management plans for the coming decades, it is essential that they incorporate estimates of chemotherapy demand, cancer physician workforce requirements, radiation oncology demands, palliative care needs, surgical oncology needs, pathology services, and nursing requirements to ensure that they comprehensively meet the needs of patients.

The rising global cancer burden is undoubtedly one of the major health crises of today. Strategies are urgently needed to equip the global health force to enable safe treatment of current and future patients and ensure the basic human right of access to appropriate health care. As a first step, countries and institutions can use our data to estimate cancer physician workforce requirements and chemotherapy needs in the future to plan national, regional, and global development strategies.

References
1 Bray F, Ferlay J, Soerjomataram I, Siegel RL, Torre LA, Jemal A. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin* 2018; **68:** 394–424.
2 Ferlay JEM, Lam F, Colombet M, et al. Cancer tomorrow. http://gco.iarc.fr/tomorrow (accessed Jan 28, 2019).
3 Gakwaya A, Kigula-Mugambe JB, Kavuma A, et al. Cancer of the breast: 5-year survival in a tertiary hospital in Uganda. *Br J Cancer* 2008; **99:** 63.
4 Yang L-L, Zhang X-C, Yang X-N, et al. Lung cancer treatment disparities in China: a question in need of an answer. *Oncologist* 2014; **19:** 1084–90.
5 Elferink M, Wouters M, Krijnen P, et al. Disparities in quality of care for colon cancer between hospitals in the Netherlands. *Eur J Surg Oncol* 2010; **36:** S64–73.
6 Ayanian JZ, Zaslavsky AM, Fuchs CS, et al. Use of adjuvant chemotherapy and radiation therapy for colorectal cancer in a population-based cohort. *J Clin Oncol* 2003; **21:** 1293–300.
7 WHO. Cancer prevention and control in the context of an intergrated approach. Geneva: World Health Organization, 2017.
8 Atun R, Jaffray DA, Barton MB, et al. Expanding global access to radiotherapy. *Lancet Oncol* 2015; **16:** 1153–86.
9 Yap ML, Hanna TP, Shafiq J, et al. The benefits of providing external beam radiotherapy in low- and middle-income countries. *Clin Oncol* 2017; **29:** 72–83.
10 Yap ML, Zubizarreta E, Bray F, Ferlay J, Barton M. Global access to radiotherapy services: have we made progress during the past decade? *J Glob Oncol* 2016; **2:** 207–15.
11 Ferlay J, Soerjomataram I, Dikshit R, et al. Cancer incidence and mortality worldwide: sources, methods and major patterns in GLOBOCAN 2012. *Int J Cancer* 2015; **136:** E359–86.
12 World Bank. Wold Bank country and lending groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519 (accessed Jan 20, 2019).
13 Jacob SA, Ng WL, Do V. Estimation of an optimal chemotherapy utilisation rate for cancer: setting an evidence-based benchmark for quality cancer care. *Clin Oncol* 2015; **27:** 77–82.
14 Fundytus A, Sullivan R, Vanderpuye V, et al. Delivery of global cancer care: an international study of medical oncology workload. *J Glob Oncol* 2017; **4:** 1–11.
15 Cancer Care Ontario. The Systemic Task Force Report 2000. https://archive.cancercare.on.ca/common/pages/UserFile.aspx?fileId=14436 (accessed Nov 12, 2018).
16 Blinman PL, Grimison P, Barton MB, et al. The shortage of medical oncologists: the Australian medical oncologist workforce study. *Med J Aust* 2012; **196:** 58–61.
17 Jacob S, Ng W, Asghari R, Delaney GP, Barton MB. Estimation of an optimal chemotherapy utilisation rate for colon cancer: an evidence-based benchmark for cancer care. *Eur J Cancer* 2009; **45:** 2503–09.
18 Sullivan R, Alatise OI, Anderson BO, et al. Global cancer surgery: delivering safe, affordable, and timely cancer surgery. *Lancet Oncol* 2015; **16:** 1193–224.
19 Farmer P, Frenk J, Knaul FM, et al. Expansion of cancer care and control in countries of low and middle income: a call to action. *Lancet* 2010; **376:** 1186–93.
20 Mathew A. Global survey of clinical oncology workforce. *J Glob Oncol* 2018; **4:** 1–12.
21 American Society of Clinical Oncology. Facts and figures: diversity in oncology 2018. https://www.asco.org/practice-guidelines/cancer-care-initiatives/diversity-oncology-initiative/facts-figures-diversity (accessed Nov 12, 2018).
22 Yang W, Williams JH, Hogan PF, et al. Projected supply of and demand for oncologists and radiation oncologists through 2025: an aging, better-insured population will result in shortage. *J Oncol Pract* 2014; **10:** 39–45.
23 Erikson C, Salsberg E, Forte G, Bruinooge S, Goldstein M. Future supply and demand for oncologists: challenges to assuring access to oncology services. *J Oncol Pract* 2007; **3:** 79–86.
24 WHO. Pricing of cancer medicines and its impacts. Geneva: World Health Organization, 2018.
25 Horton S, Gauvreau CL. Cancer in low- and middle-income countries: an economic overview. In: Gelband H, Jha P, Sankaranarayanan R, et al, eds. Cancer: disease control priorities. Washington, DC: International Bank for Reconstruction and Development and the World Bank, 2015: 263–80.
26 WHO. 'Best buys' and other recommended interventions for the prevention and control of noncommunicable diseases. Geneva: World Health Organization, 2018.
27 Borras JM, Lievens Y, Dunscombe P, et al. The optimal utilization proportion of external beam radiotherapy in European countries: an ESTRO-HERO analysis. *Radiother Oncol* 2015; **116:** 38–44.
28 Shulman LN, Willett W, Sievers A, Knaul FM. Breast cancer in developing countries: opportunities for improved survival. *J Oncol* 2010; **2010:** 1–6.
29 Chopra R. The Indian scene. *J Clin Oncol* 2001; **19** (suppl 18): 106S–11S.
30 Iqbal J, Ginsburg O, Rochon PA, Sun P, Narod SA. Differences in breast cancer stage at diagnosis and cancer-specific survival by race and ethnicity in the United States. *JAMA* 2015; **313:** 165–73.
31 Salem AA, Salem MAE, Abbass H. Breast cancer: surgery at the south Egypt cancer institute. *Cancers* 2010; **2:** 1771–78.
32 Jedy-Agba E, McCormack V, Adebamowo C, dos-Santos-Silva I. Stage at diagnosis of breast cancer in sub-Saharan Africa: a systematic review and meta-analysis. *Lancet Glob Health* 2016; **4:** e923–35.
33 Piñeros M, Parkin DM, Ward K, et al. Essential TNM: a registry tool to reduce gaps in cancer staging information. *Lancet Oncol* 2019; **20:** e103–11.
34 Ng WL. Estimating the optimal chemotherapy utilisation rate as an evidence-based benchmark in cancers of the breast, upper gastrointestinal tract, gynaecological tract, head and neck, kidney, bladder, thyroid and unknown primary. PhD thesis, University of New South Wales, 2010.
35 Ku G, Tan IB, Yau T, et al. Management of colon cancer: resource-stratified guidelines from the Asian Oncology Summit 2012. *Lancet Oncol* 2012; **13:** e470–81.

36   Shen L, Shan Y-S, Hu H-M, et al. Management of gastric cancer
      in Asia: resource-stratified guidelines. *Lancet Oncol* 2013;
      14: e535–47.

37   El Saghir NS, Adebamowo CA, Anderson BO, et al. Breast cancer
      management in low resource countries (LRCs): consensus
      statement from the Breast Health Global Initiative. *Breast* 2011;
      20 (suppl 2)**:** S3–S11.

38   Williams S, Chiong E, Lojanapiwat B, Umbas R, Akaza H.
      Management of prostate cancer in Asia: resource-stratified
      guidelines from the Asian Oncology Summit 2013. *Lancet Oncol*
      2013; **14:** e524–34.