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Supplementary appendix

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Web Appendix

This appendix supplement to:
The *Lancet* Commission on Diagnostics Report

Web Appendix Panel 1: Diagnostic Investigation (Test or Examination) Definitions
The following terms were used for the different test purposes: [1]

- Screening test: Screening tests are used to determine the status of a disease, disorder or other physiological state in an asymptomatic individual. Depending on the nature of the condition and the targeted patient population, screening tests may be used routinely or may be restricted to 'at risk' patients. These tests are designed to evaluate an individual's current state.
- Diagnostic test: Diagnostic tests are used to determine, verify or confirm a patient's clinical condition as a sole determinant. This type of testing also includes sole confirmatory assays (to verify results of previous testing) and sole exclusion assays (to rule out a particular condition). These tests are designed to evaluate a patient's current state.
- Aid to diagnosis: Tests that are used as aids to diagnosis provide additional information to assist in the determination or verification of a patient's clinical status. The test is not the sole determinant. These tests are designed to evaluate a patient's current state.
- Monitoring test: Monitoring tests are used for measuring levels of analytes for the purpose of adjusting treatments or interventions as required. Monitoring tests include: – Assays which are used to ensure that an analyte remains within physiological levels or within an established therapeutic drug range. These types of monitoring tests are designed to evaluate an individual's current state. – Assays which are used for serial measurement, whereby multiple determinations are taken over time. These types of monitoring tests are typically used for the detection/assessment of disease progression/regression, disease recurrence, minimum residual disease, response/resistance to therapy, and/or adverse effects due to therapy. These types of monitoring tests are designed to evaluate changes in an individual's state.
- Prognostic tests: These tests are used to measure factors linked to clinical outcome irrespective of treatment. Such tests may be used to estimate the natural progression of a disease (i.e. outcome in the absence of treatment), or to determine the likelihood of a clinical outcome irrespective of therapeutic intervention. These tests are designed to evaluate a patient's future state.
- Surveillance test: Performed on populations of interest to track the progression of disease incidence and/or prevalence.
- Staging test: Performed on patients with a confirmed disease or condition to determine its state at the time of diagnosis and establish a baseline to make relevant treatment decisions.

Web Appendix Panel 2: Summary of systematic reviews on improving demand for diagnostic testing

Strategy	Evidence from systematic reviews
Make testing available in the community	HIV testing in sub-Saharan Africa [2]
	HIV testing in various LMICs [3]
	TB testing in hard-to-reach populations in Europe and OECD [4]
	Dried blood spot tests for hepatitis C in high-risk populations in high income countries [5,6]
Offer self-testing	HIV testing in Africa [7] and in five LMICs with a range of income levels [8]
Use participatory social media (online communities)	Social media interventions for HIV [9]
Use conventional media/letter campaigns not found to be particularly effective	Culturally-sensitive initiatives for cancer screening in Asian women [10]; messages on HIV aimed at migrants [11]
Training primary care practitioners on encouraging or better explanation of testing	Hepatitis C testing in high risk groups [5]; better explanation of importance of post-partum testing for diabetes, for mothers who developed gestational diabetes [12]
Teaching practitioners re appropriate attitude when testing for stigmatized diseases/testing marginalized groups	TB testing for hard-to-reach groups in Europe [4], and in marginalized communities [13].
Using sensitivity when using provider-initiated testing	HIV testing in concentrated economics [11]
Sending reminders for follow-up testing	Hepatitis C [14]; Postnatal glucose testing [12]; breast cancer screening [10]

Web Appendix Panel 3: Diagnosis: the biggest gap in the cascades of care: technical details

A scoping search was undertaken on PubMed for several tracer conditions, communicable as well as non-communicable, to first identify published literature on these models. Care cascades were retrieved care cascades for diabetes, [15-18] hypertension, [19-21] tuberculosis, [22-25] HIV, [26,27] Hepatitis B,[28] malaria [29] and maternal and child health care. [30] Wherever we found studies that provided pooled analyses of individual- level data globally or multi-country data or data for low-middle income countries (LMICs), we present those results in Figure 1 and Table 1. We also included studies if the authors constructed cascade of care using standardized approaches.[31,32] If we found no global data, we present the range of the results from the available studies.

Diabetes

- Screened: where patients got at least one blood sugar test done
- Diagnosis: where patients were diagnosed to have diabetes
- Lifestyle modification/counselling: where diagnosed patients were counselled on dietary habits and other lifestyle modifications
- Treated: where required patients are put on treatment
- Controlled: where treated patients are under good glycemic control

Hypertension

- Screened: where patients got their blood pressure (BP) tested at least once
- Diagnosis: where patients were diagnosed to have hypertension
- Treatment: where patients with confirmed diagnosis of hypertension were put on treatment
- Controlled: patients who comply with treatment and a mean blood pressure of < 140/90 mm Hg

Active tuberculosis

- Access to diagnostic tests: where suspected patients reach health facilities to get tested
- Diagnosed: where patients get tested for active TB
- Treatment started: where confirmed diagnosed patients were put on anti-TB treatment
- Treatment completed: where patients who started treatment completed the course of treatment

HIV infection

- Diagnosed: where patients reach health facilities to get tested
- Linked-to-care: where patients got at least one HIV-related visit
- Treatment initiation: where confirmed diagnosed patients were put on anti-retroviral therapy (ART)
- Retained in care: where patients who started treatment did follow-up HIV-related visits
- Virally suppressed: undetectable HIV RNA load

Hepatitis B virus infection

- Diagnosed: tested (antibody test)
- Treated or controlled: where patients are linked-to-care and have HBV antiviral treatment or yearly HBV DNA viral load testing

Maternal and newborn health

- Diagnosed: having the four ante-natal care visits at which WHO (2016) recommends eight key diagnostic tests.
- Treatment: having a skilled attendant at the birth.

Table 3.1. Studies included for each condition with diagnostic and treatment gap

Tracer condition	Number of studies	Diagnostic gap*	Treatment Gap#	Study description
Diabetes	4	56%[17]	6%[17]	Manne-Goehler 2016: in 12 Sub-Saharan African countries[15] Stokes 2017: in South Africa[16] Manne-Goehler 2019: in 28 LMICs[17] Prenissl 2019: in India[18]
Hypertension	3	61%[21]	9%[21]	Berry 2017: in South Africa[19] Prenissl 2019: in India[20] Geldsetzer 2019: in 44 LMICs[21]
Tuberculosis	4	35%[24]	5%[24]	Subbaramman 2016: in India[22] Naidoo 2017: in South Africa[23] Kim 2019: in 183 high TB burden and non-high TB burden countries [24] Mwangwa 2017: in Kenya and Uganda[25]
HIV	2	46%[26]	13%[26]	Levi 2016: global[26] Vourli 2018: in Greece[27]
Hepatitis B	1	43%[28]	44%[28]	Allard 2014: in Australia[28]
Malaria	1	62%[29]	20%[29]	Macarayan 2019: in 25 LMICs [29]
MNCH**	1	62%[30]	10%[30]	Singh 2016: in 9 countries (Bangladesh, Ethiopia, Malawi, Nepal, Pakistan, Rwanda, Senegal, Tanzania, Uganda)[30]

HIV: Human immunodeficiency virus; Hep B: hepatitis B;MNCH: maternal, newborn and child health

*Diagnostic gap: it refers to the number of patients lost in the care cascade before they reach the diagnostic step. Diagnosis was defined as a step where the test was performed, and a measurable test result was provided for the patients, unlike the screening step in some studies[3,7] where it was self-reported without any test report being provided.

#Treatment gap: It refers to the number of patients lost in the care cascade who get diagnosed but are not provided with appropriate treatment.

Web Appendix Panel 4: Modelling the health impact of reducing diagnostic and treatment gaps in LMIC

Estimating the reduction in the burden of disease in LMICs by reducing the diagnostic gap.
Assume for a chronic condition (which is never cured) – eg. Diabetes, CVD (for which hypertension is a risk) and HIV, the following:

B=burden (in LMICs) due to a condition (in DALYs or deaths) in a population with POP people
b=burden per person with the untreated condition
r=reduced risk with treatment compared to no treatment (range is zero to one, meaning zero is full risk reduction)
t=proportion of those diagnosed who are treated
d=proportion of population who are diagnosed
k=fraction of those diagnosed, who are treated hence t=kd

Then $B = (POP) \times [(1-t) + tr] \times b$

We use this to compare B_1 initial burden with current level of diagnosis and treatment, to B_2 the burden with a higher fraction of the population with the condition diagnosed.

Web Appendix Panel 5: Detailed methods for analysis of geographic access to diagnostics
Estimating Travel Time

Travel time was estimated using the web-based World Health Organization-supported Access Mod 5's geographic accessibility tool. [31,32] The tool takes geographic datasets with facility locations, climate, land cover, elevation, road networks, and water barriers as inputs, and generates a gridded surface with cells corresponding to 1km by 1km squares. We harmonized projections of input vector (line, polygon-based data) and raster (gridded data) for ten geographic regions and countries (Bangladesh, Kenya, Malawi, Namibia, Rwanda, Senegal, South Africa, Tanzania, United States of America: Colorado, Texas).

Facility data for all sub-Saharan African countries were obtained using Maina et al.'s comprehensive facility database. [33] We grouped facilities by their level of the health system (dispensaries, health centers, district hospitals, national/referral hospitals), corresponding to increasing levels of diagnostic capacity. [34] Facility data for Bangladesh were obtained using the 2014 Service Provision Assessment database. [35] Facility data for the United States were obtained from ESRI Business Analyst for the year 2008.

Road network data were obtained from the Socioeconomic and Data Applications Center Global Roads Open Access Data Set, compiled between 1980 to 2010.[36] For the United States, we used ESRI's StreetMap USA dataset.

The remaining geographic datasets were obtained from public satellite data repositories and local government databases. Sources of the different geographic dataset inputs are provided in the following table.

Table 5.1. Geographic Data Sources

Database name	Access Mod 5 Geographic Input	Source
MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid (MCD12Q1 v006)	Land cover	USGS Friedl & Sulla-Menashe 2019. Available through Google Earth Engine.
Columbia SEDAC gROADSv1	Roads	Center for International Earth Science Information Network (CIESIN)/Columbia University, and Information Technology Outreach Services (ITOS)/University of Georgia. 2013. Global Roads Open Access Data Set, Version 1 (gROADSv1).
StreetMap USA	Roads	ESRI ArcGIS StreetMap USA. Proprietary dataset.
World Pop Project	Population per 100m [32]	World Pop Project Population Counts
GMTED 2010: Global Multi-resolution Terrain Elevation Data	Elevation in 2010	Global Multi-resolution Terrain Elevation Data 2010 courtesy of the U.S. Geological Survey
ESRI hydrolines and hydropolys	Line files for rivers and lake boundaries for each country	ESRI ArcGIS catalog
Maina spatial database of facility locations (sub-Saharan Africa)	Health facility locations	Maina et al. 2019
SPA 2014 (Bangladesh)	Health facility locations	Measure DHS. Bangladesh SPA 2014. Available at: https://dhsprogram.com/data/dataset/Bangladesh_SPA_2014.cfm?flag=0https://dhsprogram.com/data/dataset/Bangladesh_SPA_2014.cfm?flag=0
Primary hospital locations (United States of America)	Health facility locations	ESRI ArcGIS Business Analyst. Proprietary dataset.

Travel times to closest facility are estimated for each of these cells using a least cost distance algorithm. [31] Briefly, the least cost distance algorithm estimates the shortest time it would take to move from one location to another within a gridded surface. Each cell in the grid is assigned a mode of travel and travel speed by the user, and an elevation correction. Our assumptions are included in the following table.

Table 5.2. Travel speed and modes of transport for land cover classifications in Access Mod 5

Land cover classification	Speed (km/hr)	Mode of transport
Evergreen Needle Leaf Forests	2	Walking
Evergreen Broad Leaf Forests	2	Walking
Deciduous Needle Leaf Forests	2	Walking
Deciduous Broad Leaf Forests	2	Walking
Mixed Forests	2	Walking
Closed Shrublands	4	Walking
Open Shrublands	4	Walking
Woody Savannas	2	Walking
Savannas	6	Walking
Grasslands	6	Walking
Permanent Wetlands	2	Walking
Croplands	6	Walking
Urban and Built up Lands	15	Bicycle
Croplands Natural Vegetation	6	Walking
Permanent snow and ice	0	Walking
Barren	6	Walking
Water bodies	0	Nothing
Unspecified	20	Motorized
Highway	100	Motorized
Primary	100	Motorized
Local/Urban (Malawi)	40	Motorized
Secondary	60	Motorized
Tertiary	40	Motorized
Trail	20	Motorized

Estimating Percent of Population within Two Hours of Testing Facility

We estimated the percent of population within two hours of a testing facility by overlaying the gridded travel time raster and the gridded population counts obtained from the World Pop Project. [37] Briefly, these population counts are estimated using random forest models with geographic and socioeconomic inputs. We aggregated the 100m x 100m population count raster to 500m x 500m to match the resolution of the travel time to closest facility rasters generated by Access Mod 5 and used a mask to characterize the area in which estimated travel times were two hours or less. We then counted the number of people in the masked area (number of people within two hours), and divided by the total population in the country to obtain the percentage of the population within two hours of a given facility type. All analyses were done using R version 3.6.3.

Estimating Testing Coverage

For Malawi, we had a complete census of testing availability by facility, but we did not have these data for Senegal. For Senegal, we linked the spatial data on testing availability from the SPA 2012 database to the more complete list of health facilities provided by the Maina et al. 2019 public database.[33] In order to do this, we needed to develop a procedure for merging testing values from the SPA database [38,39] to the Maina database. We chose to link this information based on level of facility (hospital, health center, or dispensary) and proximity. For example, if a Maina health center was not captured in the SPA database, we assumed that the Maina health center had the same test availability as its closest neighboring health center.

In order to do this, we created Thiessen polygons using the hospital, health center, and dispensary points data in the SPA database. Thiessen polygon boundaries define areas containing each point such that all of the points within the polygon are closest to the point of interest. These Thiessen polygons were used to define neighboring facilities in the Maina database. We then used a spatial polygon to point join to merge testing values from the SPA database to all neighboring Maina facilities of the same facility type.

For both Malawi and Senegal, in order to link testing availability to population counts within 2 hours of a facility, we estimated the number of people in each geographic region, i.e. county (n=256) in Malawi, and commune (n=433) in Senegal within 2 hours in Access Mod 5. This method uses the travel time estimates we obtained (and have described previously), along with the polygon boundaries of each geographic region of interest. This procedure produced a table with estimated number of people within 2 hours of a facility in each of the geographic regions. To link this data with testing availability, we performed a spatial join in ArcMap, obtaining total counts of facilities and

the number of facilities with each diagnostic tests for each county or commune. To estimate our coverage probability, we first multiplied the estimated population within 2 hours of facility for each commune by the proportion of facilities with tests available in that commune, and summed over all communes. This provided an estimate of the numerator (total number of people within two hours of a particular test). For our denominator, we summed over the total population for each county or commune to obtain an estimate of the total population in the country. This proportion served as our coverage probability.

Web Appendix Panel 6: The future Global Burden of Disease

Methodology

Two authors (MK and PA) independently extracted information on the top 20 health conditions globally, in terms of YLLs and deaths from https://vizhub.healthdata.org/gbd-foresight/. Data for LMICs were extracted from the website for the 138 countries classified as LMICs in 2018 according to the World Bank classification (World Bank, n.d.) (currently the database does not provide a separate group for LMICs). The top 20 conditions were then merged to give one consolidated list for both years. In some cases, the database uses slightly different terms for essentially similar conditions (Alzheimer's disease and Alzheimer's and related dementias; diabetes and diabetes mellitus for example). For this analysis we retained the terms used in the database but treated these as the same condition.

Web Appendix Panel 7: Share of imaging in health expenditure
A non-systematic search did not yield any data on the share of imaging in health expenditures. Whereas laboratories in hospitals function as units, imaging occurs in a more distributed format and this may help explain why data are difficult to obtain. Hospitals are typically reimbursed not for individual imaging procedures but instead based on numbers of patients by diagnosis-related groups.

Two sources were identified for information on imaging expenditures for high-income countries, both for expenditures outside hospitals. One series was data for Medicare expenditures on physician-provided services to outpatients (Medicare is the largest single provider of care in the US). The share of imaging was 21% in 2008 and declined gradually to 12% in 2017 due to legislation designed to curb these expenditures. [40] The US is, however, an outlier in the share of health spending on imaging. Data from the OECD for 2018 show that the US provides significantly more both CT scans per '000 population than all other OECD countries, and more MRI examinations per '000 population than all but two other OECD countries. [41,42] Comparative data on use of the less costly imaging technologies (ultrasound and X-ray) are not available from OECD.

The OECD data also show that there are considerable differences across countries in the proportion of scans occurring in ambulatory care versus in hospitals (see Figure 7.1). Some countries such as Australia provide the vast majority of CT and MRI scans in ambulatory care, whereas others such as Korea provide the vast majority of these same scans in hospitals. Hence the OECD data on share of "ancillary services" (largely laboratory services and imaging) in health expenditures on outpatient services are not comparable across countries. For example, that share in Australia in 2018 was 6.2%, compared to 1.5% in Korea, while the number of MRI examinations per '000 population was comparable in both countries and the number of CT scans was higher in Korea.

Figure 7.1. Computed Tomography (CT) scans, OECD countries, in ambulatory care and in hospitals, per '000 population, most recent year [41]

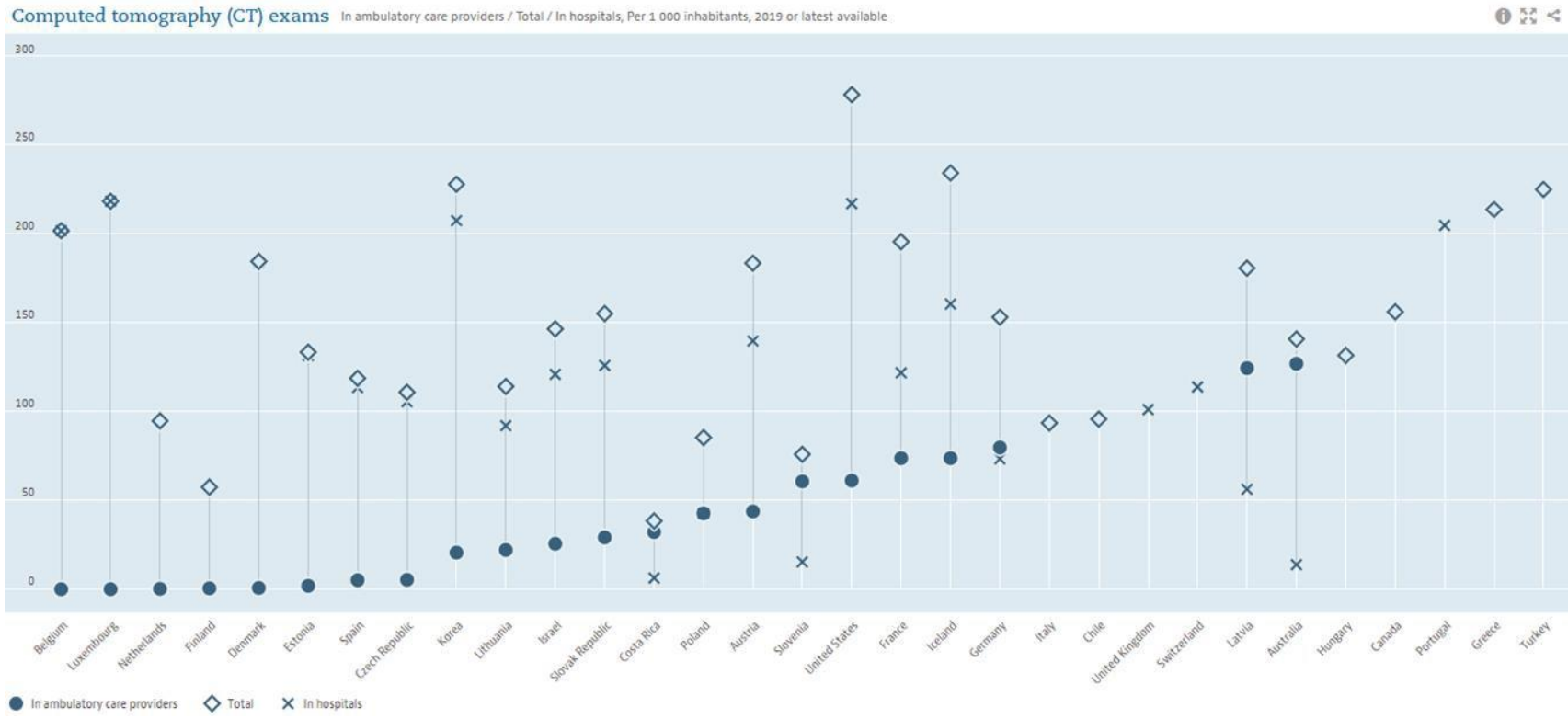

Table 7.1. Share of ancillary services (primarily laboratory and imaging services) in health expenditures in ambulatory care, OECD countries, 2018 or most recent year available

Country	% share	Country	% share
Australia	0.6*	Latvia	0.6
Austria	0.3	Lithuania	0.4
Belgium	0.5	Luxembourg	0.3
Canada	0.4	Mexico	0.1
Czech Republic	0.4	Netherlands	0.2
Denmark	0.5	Norway	0.8
Estonia	0.7	Poland	0.2
Finland	0.3	Portugal	0.7
France	0.6	Slovak Republic	0.5
Germany	0.6	Slovenia	0.3
Greece	0.2	Spain	0.4
Hungary	0.4	Sweden	0.5
Iceland	0.2	Switzerland	0.5
Ireland	0.2	United Kingdom	0.2
Italy	0.7	Costa Rica (non-OECD)	0.5
Japan	0.1*		

*2017 data

Source: calculated using OECD Health Data, 2020, found at: https://stats.oecd.org/Index.aspx?DataSetCode=SHA

Web Appendix Panel 8: Global diagnostic market

Table 8.1. Market Size and Projections for IVD, Imaging, and Pharmaceutical Sectors

	2019 Market Size (USD)	Projected Market Size (USD)	CAGR (%)
IVD	$60.8 Bn[42]	$87.11 Bn (2026)[43]	4.4 (2020 - 2027) [42]
Point of Care	$31.1 Bn [44]	$50.51 Bn (2026) [45]	10.4 (2019 - 2024) [46]
Molecular	$8.38 Bn [47]	$15.94 Bn (2027) [47]	8.4 (2019 - 2027) [47]
Imaging	$34.72 Bn [48]	$51.18 Bn (2025) [48]	5.7 (2020 - 2025) [48]
Pharmaceuticals	$843 Bn [49]	$1,181 Bn (2024) [49]	6.9 (2019 - 2024) [49]

Note: Due to data limitations, a variety of sources were used over a range of years, depending on data availability

Table 8.2. Percentage share of global diagnostic/pharmaceutical purchases, by region

Region	In-vitro diagnostics 2017[50]	Medical imaging 2015[51]	Pharmaceuticals 2017[52]
North America	43 (USA)	33.4 (USA, Canada)	36 (USA, Canada)
Europe	34	30 (Germany, Netherlands, Italy, Hungary, Denmark)	22 (Western Europe)
Asia-Pacific	15[53]	25.4[54] (China, Japan, South Korea)	23 (China, Japan, South Korea, Australia, Saudi Arabia), of which 10 (China), 13 (other high-income)
Rest of the world	11	11.2	19 (Latin America, Russia, India, Indonesia, Rest of world)

Table 8.3. Market Share of Major Players for In-Vitro Diagnostics, Pharmaceutical companies, and Medical diagnostic imaging

Major Players					
IVD [55]	**Market Share (%)**	**Pharmaceutical [56,49]**	**Market Share (%)**	**Imaging [51]**	**Market Share (%)**
Roche (Europe)	19	Pfizer (USA)	6	GE Healthcare (USA)	23
Abbott (USA)	13	Roche (Europe)	6	Siemens Healthcare (Europe)	21
Danaher (USA)	9	Novartis (Europe)	6	Philips Healthcare (Europe)	18
Siemens (Europe)	8	Merck & Co (USA)	6	Toshiba Medical Systems (Asian-Pacific)	13

Web Appendix Panel 9: Workforce Projections: Methods for Calculating Proportion of Global Healthcare Workforce in Diagnostics

Developing estimates of gaps in global health workforce capacity require making several assumptions. The first of these is that the most comprehensive data that can be used to establish benchmarks (i.e., optimal staffing levels) are from HIC. It is not expected that health care systems in LMIC will need to achieve equivalent staffing levels in order to successfully provide UHC. Second, HIC often have a number of health care providers to fill specific health care roles that may be provided by other types of health care workers in LMIC, reducing the need for total workforce capacity. Last, the US and UK were selected to compare one market-based health care system against a national health care system. Countries moving to implement UHC are likely to use national health care systems, making the UK data more relevant.

Definitions

The term 'pathologist' means different things in different places due to varying models of training and practice. For purposes of our analysis, we were inclusive of anatomic (US term)/cellular (UK term) pathologists, physicians who practice laboratory medicine (clinical pathology in the US, divided into individual subspecialties in the UK), and those who do both (primarily in the US). Although we included as many non-physician doctoral scientists who work in laboratory medicine as we could identify, we understand that some may not have been included. In the same way, we were inclusive when using the term 'radiologist' to include any physician trained to practice in the field of medical imaging, without regard to specialization. One important challenge in HIC is the issue of sub-specialization and estimating diagnostic capacity: sub-specialists typically do not perform general pathology or general medical imaging services, and do not perform other specialty services, so sub-specialization could lead to over-estimates of diagnostic capacity. Although there is a general understanding of the meaning of the terms 'pathologist' and 'radiologist', there are other and related terms in the literature than may confuse readers: radiographers, pathology assistants, laboratory scientists, ultrasonographers, and others. These need to be carefully defined, with descriptions of their roles, for analysis and planning for workforce capacity.

Methodology

For the US model, data from the US Bureau of Labor Statistics for all Healthcare Practitioners and Technical Occupations, [57] those for Healthcare Support Occupations, [58] and one recent publication [59] regarding the pathologist and radiologist workforces were used to calculate the total healthcare workforce. Several occupations (e.g., those involved in veterinary care) were then deducted from the total to yield a total healthcare workforce involved in human health. Next, the categories of healthcare workers involved in PALM and medical imaging were calculated. These two numbers were then used to calculate the percentage of the US healthcare workforce involved in PALM and medical imaging. As a final step, these percentages were used to calculate potential global workforce shortages in PALM and medical imaging for 2030 using the WHO estimates of total workforce shortages of 15-18,000,000 persons.

For the UK model, data from the NHS Workforce Statistics – February 2020 [60] were used for all healthcare workers, supplemented from two publications [61,62] on PALM workforce. The same methodology was used as described for the US model.

US Model
The two Major Groups for healthcare employment are as follows:

1. Occupational Employment and Wages, May 2019
29-0000 Healthcare Practitioners and Technical Occupations (Major Group) [57-59]
This major group comprises the following over 70 different occupations

Table 9.1. National estimates for this occupation:
Employment estimate and mean wage estimates for this major group:

Employment	Employment RSE	Mean hourly wage	Mean annual wage	Wage RSE
8,673,140	0.3 %	$40.21	$83,640	0.2 %

2. Occupational Employment and Wages, May 2019
31-0000 Healthcare Support Occupations (Major Group)
This major group comprises 18 occupations

Table 9.2. National estimates for this occupation*:*
Employment estimate and mean wage estimates for this major group:

Employment	Employment RSE	Mean hourly wage	Mean annual wage	Wage RSE
6,521,790	0.3 %	$14.91	$31,010	0.2 %

Total Employment:

29-0000 Healthcare Practitioners and Technical Occupations:	8,673,140
31-0000 Healthcare Support Occupations:	6,521,790
Total	15,194,930

The following categories were deducted from the total:

29-1131 Veterinarians:	74,540
29-2056 Veterinary Technologists and Technicians:	110,650
31-9096 Veterinary Assistants and Laboratory Animal Caretakers:	97,030
Total	282,220

Revised Total US Healthcare Workforce 15,194,930 – 282,220 = 14,912,710

Occupations Used to Estimate US PALM Workforce:

29-2010 Clinical Laboratory Technologists and Technicians:	326,020
31-9097 Phlebotomists	128,290
Pathologists (data from Metter, 2019)	12,838
Total	467,148

Occupations Used to Estimate US Medical imaging Workforce:

29-2032 Diagnostic Medical Sonographers	72,790
29-2033 Nuclear Medicine Technologists	18,110

29-2034 Radiologic Technologists and Technicians	207,360
29-2035 Magnetic Resonance Imaging Technologists	37,900
Radiologists (data from Metter, 2019)	27,719
Total	363,879
Total US Healthcare Workforce:	14,912,710
Proportion in PALM:	467,148/14,912,710 = 3.13%
Proportion in Medical imaging:	363,879/14,912,710 = 2.44%

Calculations for Projected Shortages in PALM and Medical imaging by 2030

WHO Estimates of Global Healthcare Workforce Shortages

Shortage of all healthcare worders	15,000,000
Proportion PALM (3.13%)	469,500
Proportion medical imaging (2.44%)	366,000
Total	835,500
	18,000,000
Proportion PALM (3.13%)	563,400
Proportion medical imaging (2.44%)	439,200
Total	1,002,600

NHS England Model [61-63]

NHS Staff (2020 FTE)	1,134,824
Estimated Pathology Workforce in England	
(Satta 2015 data)	28,886
(Cancer Research UK 2014 data)	30,837
Estimated medical imaging Workforce in England	
(Digital NHS 2020 Data)	24,520
Total UK Healthcare Workforce:	1,134,824
Proportion in PALM:	28,886/1,134,824 = 2.55%
Proportion in medical imaging:	24,520/1,134,824 = 2.16%

Calculations for Projected Shortages in PALM and Medical imaging by 2030

WHO Estimates of Global Healthcare Workforce Shortages

	15,000,000
Proportion PALM =	382,500
Proportion medical imaging =	324,000
Total	706,500

	18,000,000
Proportion PALM =	459,000
Proportion medical imaging =	388,800
Total	847,800

Summary Calculations for the Two Models: Global Workforce Shortages in PALM and Medical Imaging by Year 2030

US Model:	835,500-1,002,600
UK NHS Model:	706,500-847,800

Web Appendix Panel 10: Modelled GBD-20 EDL
Table 10.1 Detailed list of tests/examinations by tier

Service	Primary	Secondary	Tertiary
Chemistry	RDT: Human chorionic gonadotropin; ESR/CRP; Fecal Immunochemical Test; Fecal occult blood Glucometer: Glucose	Automated chemistry analyzer: Albumin; alpha-1 antitrypsin deficiency; Amylase*; Calcium; Creatine kinase; Creatinine clearance*; Electrolytes (Na, K, Cl)*; Glucose*; Haptoglobin*; Lactate dehydrogenase*; Lipase*; Lipid panel*; Liver function*; Magnesium; Phosphorus*; Renal function*; Uric acid*; Urine albumin/creatinine; Urine protein/creatinine; Vitamin B12 Automated immunoassay analyzer: B-type natriuretic peptide; Human chorionic gonadotropin*; ESR/CRP*; Cardiac marker; TSH Benchtop/handheld analyzer: Blood gas; Cooximetry*; HbA1c*; Cardiac marker	Automated immunoassay analyzer: Vitamin D, hydroxy (25); Alpha-fetoprotein; CA 19-9; Carcinoembryonic antigen (CEA); Iron deficiency panel; Ketones; Parathyroid hormone Automated chemistry analyzer: Alkaline phosphatase; High performance liquid chromatography: HbA1c** Benchtop/handheld analyzer: Lactate Osmometer: Osmolality, plasma
Hematology	RDT: G6PD enzyme testing Hemoglobinometer: Hemoglobin Urine Dipstick: Urinalysis	Automated hematology analyzer: CBC*; CSF analysis (cell counts)* Automated chemistry analyzer: CSF analysis (glucose, protein)* Microscopy, with stains: Fecal leukocytes*; Urinalysis, microscopic Hematology smear microscopy: CBC; CSF analysis (microscopy, cell counts)*	Semi-quantitative fluorescent spot test: G6PD enzyme testing**
Microbiology	RDT: antigen, Malaria; serology, Dengue fever; serology (HCV, HIV, Syphilis); TB Lipoarabinomannan, urine (LF-LAM) microscopy, Malaria	Microscopy, with stains: Microscopy for microorganisms (gram, AFB, iodine, trichrome, india ink, KOH, etc.)* Microscopy, ova and parasites* Benchtop/handheld analyzer: Qualitative HIV virological (RNA, DNA, or US p24 Ag)*; HIV RNA quantitative*; nucleic acid testing, Tuberculosis* Automated immunoassay analyzer: serology (Chikungunya*; Dengue fever*; HBV*; HCV*; HIV*; Syphilis (RPR, treponemal)*; Yellow fever* ELISA: serology (Chikungunya*; Dengue fever*; Typhoid fever*; Yellow fever*)	Automated immunoassay analyzer: antigen, Entamoeba; antigen, Legionella (urine); antigen, Shiga; serology, Entamoeba RDT: antigen, Legionella (urine); antigen, Pneumococcus; antigen, Shiga culture, Bacterial**; culture, Fungal; culture, Tuberculosis** Biochemical bacterial identification Bacterial AST; TB AST**; TB Line probe assays for INH, RIF, 2nd line agents (AST)** Automated nucleic acid analyzer: nucleic acid testing, Chlamydia**; Qualitative HIV virological (RNA, DNA)**; nucleic acid testing, HIV RNA quantitative**; nucleic acid testing (N. gonorrhoeae**; Respiratory virus panel; Shiga; Tuberculosis**) Manual microbial identification: serology, Typhoid fever (Widal)**

Radiology	Ultrasound, POC	Ultrasound X-ray*	Advanced breast imaging CT scan* Fluoroscopy Basic interventional radiology* Complex interventional radiology* Mammography** MRI* Nuclear radiology PET scan
Blood bank	NA	Slide agglutination: Red blood cell typing*	Red blood cell agglutination: Direct antiglobulin test; Indirect antiglobulin test
Coagulation	NA	Automated coagulation analyzer: Antiphospholipid antibodies; Coagulation function (PT, PTT); Fibrinogen Benchtop/handheld analyzer: Coagulation function (PT, PTT); Fibrinogen Automated immunoassay analyzer: D-dimer products	Automated coagulation analyzer: anti-Xa assay (heparin)
Flow cytometry	NA	Benchtop/handheld analyzer: Lymphocyte CD4*	Flow cytometry: Lymphocyte CD4**
Histopathology	NA	NA	Microscopy, with immunohistochemistry: Immunohistopathology/Immunocytopathology Microscopy, with stains: Histopathology/Cytopathology
Immunology	NA	NA	Indirect immunofluorescence: Antinuclear antibodies, screen** Automated immunoassay analyzer: Immunoglobulins, quantitative (IgG, IgA, IgM)
Molecular (non-Microbiology)	NA	NA	Benchtop/handheld analyzer: molecular, HER2 Microscopy, with immunohistochemistry: molecular, HER2 Nucleic acid analysis: Microsatellite instability testing; molecular, Breast cancer (ER, PR, HER2); molecular, Epidermal Growth Factor Receptor
Toxicology	NA	NA	Automated chemistry analyzer: therapeutic drug monitoring (Amikacin; Gentamicin; Methotrexate)

*diagnostic is indicated at one tier below, but infrastructure limits placement there (patient referral or specimen transport required)

**diagnostic is indicated at two tiers below, but infrastructure limits placement there (patient referral or specimen transport required)

Note: all diagnostics available at lower tier levels are also available at higher tier levels but are unlisted in this table. Tests may be performed in different formats at different tiers, and placement of all formats may not be necessary.

Web Appendix Panel 11: Key data and assumptions used for calculating benefit-cost ratio for diagnosis and treatment of four conditions.

Table 11.1. Parameters used for calculations for Hepatitis B, the Gambia

Parameter	Value
Probability of a mother being HBsAg positive (uses value for all adults over 30)	0.088[63]
Probability that a HBsAg-positive and HBeAg-positive mother gives birth to an infant who is HBsAg positive	0.383[64]
Probability that a HBsAg-positive and HBeAg-negative mother gives birth to an infant who is HBsAg positive	0.048[64]
Probability that an HBsAg—positive mother is also HBeAg-positive	0.23[64]
Relative risk reduction of tenofovir	0.712
Adherence to tenofovir medication	1.00[65]
Cost of point-of-care test for HBsAg	$2.00[64]
Monthly treatment cost of tenofovir	$2.48[64]
Discount rate for costs and health outcomes	3%
Present value of DALYs averted at age 38 per birth, in a population with prevalence of testing HBsAg positive of 8.8%	0.05[63]
Present value of future treatment costs per birth in a population with prevalence of testing HBsAG positive of 8.8%	$11.15[63]
Per capita GDP, the Gambia, 2013 (same year as costs data)	$487[63]

Table 11.2. Calculation of numbers of individuals to screen for hypertension, to achieve one controlled case

Region	Prevalence	% of those hypertensive, aware	% of those hypertensive, treated	% of those hypertensive, achieving control	# to screen to get 1 additional controlled case
Middle East/ North Africa[a]	31.1%	49%	47%	19%	17
Latin America[b]	42.5%	63.0%	48.7%	21.1%	11
South Asia[c]	30.7%	51.4%	41.9%	24.5%	13
Sub-Saharan Africa[d]	35.3%	28.2%[1]	22.4%	8.9%	32

[a] Middle East/North Africa represented by Iran, Palestine, Saudi Arabia and UAR; survey in adults[66]
[b] Latin America Southern Cone represented by four cities in Argentina, Chile and Uruguay, adults 35-74, surveyed in 2010-11[67]
[c] South Asia represented by 28 states and union territories of India, adults 18+, 2015[68]
[d] Sub-Saharan Africa represented by South Africa, national survey 2010-11, adults 15+[69]
Includes only those diagnosed (slightly different question asked in South Africa)

Table 11.3. Calculation of benefit-cost ratio for hypertension, four world regions

Region	Per capita GNP 2001[8]	Cost of screening tests needed for one additional successful control[b]	Lifetime direct benefits (-ve implies net costs)[b]	Lifetime QALY gains[b]	Lifetime indirect benefits[c]	Benefit-cost ratio[c]
Middle East/ North Africa	$2969	$153 (=17 x $9)	-$261.50	0.3	$890.70	4.1: 1
Latin America & Caribbean	$4033	$99 (=11 X $9)	-$353.80	0.4	$1613.20	12.7: 1
South Asia	$452	$121 (=13 x $9)	-$171.40	0.24	$108.48	< 1
Sub-Saharan Africa	$545	$288 (=32 X $9)	-$200	0.26	$141.70	< 1

[a] $9 is median value from Table 2 in study by Gaziano et al[70] and number of tests is from table 10.2 above
[b] Author's derivation from Figure in Gaziano et al[70]
[c]Author's calculation

Table 11.4. Parameters used for calculations for type 2 diabetes, with sources

Parameter	**Value**	**Comments**
Prevalence - population ages 15+	10.1%[71] 9.8%[72]	
Cascade: % of those with diabetes who: - Were tested - Were diagnosed - Were linked to diabetes management	 64.4%[73] 44.2%[73] 40.1%[73]	
Proportion of those undergoing a single random glucose test and who are referred for diabetes diagnostic testing, who test positive for diabetes	0.2	Author's assumption (no data identified)
Cost of tests (private sector) 2019[74] - Two fasting glucose tests - Two glycated hemoglobin tests Estimated cost of tests (public sector), 2019 - Two fasting glucose tests - Two glycated hemoglobin tests	 $8.22 $32.28 $5.76 $22.60	Pathcare, 2019. Note that public sector costs are generally about 70% of private, allowing for profit
Annual cost of illness (direct medical costs) - Management cost for diagnosed patients - Cost of complications for patients without management - Cost of complications patients w' management - Cost savings for managed vs unmanaged	 $425.29 per diagnosed patient $401.44 per patient $311.12 per patient $90.32 per person	Author's calculations using[75]
Number of deaths annually from diabetes[72] mortality rate (per person 15+ with diabetes)	54,830 4.808 per '000	 Calculated from prevalence[73] and population[76] virtually no deaths under 15 with type 2 diabetes
Total number of DALYs lost annually from diabetes -Same as above, population age 15-64 - annual DALY losses per person with diabetes 15-64	754,456 438,631 0.108	Calculated from 2017 GBD data[72] Same as above Author's calculation using pop data by age[76] and diabetes prevalence[73]
-Annual DALY loss per diabetic person w' managemt -Annual DALY loss per diabetic person whose condition not managed	0.092 0.119	Assumes proportion treated/untreated in total population is same as that in 15-64 age population
Per capita GNI 2018 (USD)[8]	$5750	
-Indirect losses (USD) per diabetic w' managmt per year -Indirect losses per diabetic w'o management per year -Cost savings for managed vs unmanaged per person per year	$529 $684 $155	DALY loss per person 15-64 diagnosed with diabetes; author's calculation using methodology[78] with updated 2017 GBD data[77]
Life expectancy at birth in 2017[76]	64	

Table 11.5. Benefit-cost ratios of an intervention diagnosing and treating syphilis in pregnant women, various country scenarios.

Country Type[79]	Key parameters[79]	Intervention cost per pregnancy $[79]	Intervention healthcare Savings per pregnancy $[79]	DALYs averted per pregnancy[79]	Per capita GNP in $ of median country[8]	$ Value of DALYs averted per pregnancy	Benefit-cost ratio
A	HLL	1.08	1.57	.023371	743.40	17.374	17.5:1
B	HLH	1.35	4.41	.023371	3385.84	79.130	62.1:1
C	HHL	1.66	1.85	.008629	568.00	4.900	4.1:1
D	HHH	2.06	3.21	.008629	7257.76	62.63	32.9:1
E	LLL	1.04	0.60	.003896	1241.46	4.83	5.3:1
F	LLH	1.30	1.16	.003896	3741.38	14.57	12.1:1
G	LHL	1.59	1.43	.001439	1357.56	1.95	2.1:1
H	LHH	1.98	1.95	.001439	5227.46	7.52	4.8:1

Source: author's calculations, using[79]; assigning one DALY the value of per capita GDP[77].

Notes: US dollars of 2010 are used throughout. Column two provides values for three key parameters: prevalence of syphilis in antenatal care; current coverage of screening and treatment in ANC; and cost of health services. Each of the three are categorized as high (H) or low (L). This categorization divides low- and middle-income countries into eight archetypes, with examples of each type as follows:

Country type A: Madagascar, Tanzania, Zambia
Country type B: Equatorial Guinea, Eswatini, Indonesia
Country type C: Mozambique, Haiti
Country type D: South Africa, Namibia, Paraguay, Grenada, Chile
Country type E: Nicaragua, Myanmar
Country type F: Guatemala, India
Country type G: Cote d'Ivoire, Guyana, India
Country type H: Mauritius, Cabo Verde, Barbados, Maldives.

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