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Global Unmet Needs in Cardiac Surgery

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ABSTRACT

More than 6 billion people live outside industrialized countries and have insufficient access to cardiac surgery. Given the recently confirmed high prevailing mortality for rheumatic heart disease in many of these countries together with increasing numbers of patients needing interventions for lifestyle diseases due to an accelerating epidemiological transition, a significant need for cardiac surgery could be assumed. Yet, need estimates were largely based on extrapolated screening studies while true service levels remained unknown. A multi-author effort representing 16 high-, middle-, and low-income countries was undertaken to narrow the need assessment for cardiac surgery including rheumatic and lifestyle cardiac diseases as well as congenital heart disease on the basis of existing data deduction. Actual levels of cardiac surgery were determined in each of these countries on the basis of questionnaires, national databases, or annual reports of national societies. Need estimates range from 200 operations per million in low-income countries that are nonendemic for rheumatic heart disease to >1,000 operations per million in high-income countries representing the end of the epidemiological transition. Actually provided levels of cardiac surgery range from 0.5 per million in the assessed low- and lower-middle income countries (average 107 ± 113 per million; representing a population of 1.6 billion) to 500 in the upper-middle-income countries (average 270 ± 163 per million representing a population of 1.9 billion). By combining need estimates with the assessment of de facto provided levels of cardiac surgery, it emerged that a significant degree of underdelivery of often lifesaving open heart surgery does not only prevail in low-income countries but is also disturbingly high in middle-income countries.

The evolution of cardiac surgery after the Second World War was driven by 2 major objectives: to correct congenital heart defects and to restore the function of heart valves affected by rheumatic heart disease (RHD). As the discipline became an integral part of medicine, the growing affluence in industrialized countries led to the near disappearance of RHD and to the emergence of degenerative and lifestyle diseases as primary indications for open heart surgery. Further evolution in these high-income countries (HIC) has witnessed the increasing importance of interventional cardiology and eventually an overcapacity in cardiac surgery. The situation in the rest of the world, however, has not followed this pattern and is currently reminiscent of the earlier phases of this development. Because rheumatic fever and RHD are still prevalent there, low-income countries (LIC) often mirror the pre-cardiac

surgery era of the 1950s, whereas middle-income countries (MIC) resemble the 1970s with large metropolitan cardiac centers yet with an overall undercapacity of cardiac surgery related to the needs of the population. Regrettably, in spite of the fact that the World Health Organization predicted heart diseases to become the number one cause of death in LIC and MIC in the near future, access to cardiac surgery in these countries remains grossly insufficient or, in some cases, lacking altogether.

DATA COMPILATION

A multi-author survey was undertaken to address the scarcity of knowledge regarding both cardiac surgical needs and capabilities outside high-income regions. We have used the annual reports of national societies or contacted

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TABLE 1. Socioeconomic parameters of 16 countries (1 low income [Mozambique], 4 lower middle income [India, Nigeria, Morocco, Tunisia], 8 upper middle income [Namibia, Algeria, Iran, South Africa, Cuba, China, Brazil, Russia], and 3 high income [Germany, Singapore, United States]) opposite the number of cardiac surgical hospitals in total and broken down into public and private facilities

	Health Expenditure/yr (USD)								Cardiac Centers		
	GDP (USD)								Centers per Million Population/Population per Center		
	Population in Millions	Gini Index	Σ in Billions	Per Capita	Σ in Billions	Per Capita	% of GDP	Σ (Public/Private)	Σ	Per Public Patient Population	Per Private Patient Population
Mozambique*	29	46	11	380	0.9	79	7	2 (1/1)	<0.1/15	3*/0.3	0.03/29
India	1,330	35	2,260	1,710	106	267	5	517 (48/469)	0.4/2.2	NA	NA
Nigeria	195	43	405	2,178	15	217	4	15 (9/6)	0.08/13	NA	NA
Morocco	35	41	101	2,850	6	450	6	22 (7/15)	0.6/1.6	0.5/2.0	0.7/1.4
Tunisia	11	36	42	3,690	3	790	7	17 (5/12)	1.5/0.6	1.7/0.6	1.8/0.7
Namibia	>2	61	10	4,140	<1	869	9	2 (1/1)	0.8/1.2	0.6/1.7	1.7/0.6
Algeria [†]	41	28	156	4,270	11	932	7	23 (8/15)	0.6/1.7	0.6/1.7	0.8/1.2
Iran	80	39	404	5,050	28	1,080	7	105 (66/39)	1.3/0.7	1.2/0.8	1.6/0.6
South Africa	59	63	295	5,300	23	1,150	9	46 (8/38)	0.8/1.3	0.2/6.1	3.8/0.3
Cuba	11	41	87	7,602	10	2,475	11	6 (only public)	0.5/1.9	0.5/1.9	0
China [‡]	1,380	47	11,200	8,120	616	731	6	723 (718/5)	0.5/1.9	0.5/1.9	0.004/276
Brazil [§]	214	51	1,800	8,650	150	1,320	8	337 [§] (337/320)	1.6/0.6	1.6/0.6	8.9/0.1
Russia	149	38	1,290	8,750	92	1,840	7	119 (only public)	0.8/1.3	0.8/1.3	0
Germany [†] [16]	83	31	3,467	41,940	381	5,182	11	78 (all both)	0.9/1.1	1.0/1.0	9.4/0.1
Singapore	6	46	300	52,960	15	4,050	5	7 (3/4)	1.3/0.8	0.8/1.9	2.2/0.5
United States	323	41	18,600	57,470	3,200	>10,000	17				

Each category was expressed as per million population having access to the respective service. Σ = Total.

GDP, gross domestic product; NA, not applicable.

*Mozambique has 1 private center for its 300,000 private patients. As such, 3 per million although only 1 exists in the whole country.

[†]In Algeria private patients have also access to public hospitals.

[‡]In China and Germany all patients have access to private facilities. In Germany, all institutions have both public and private patients.

[§]In Brazil, only 5% of hospitals offering cardiac surgery are only public, all others treat public and private patients.

the heads of leading cardiothoracic departments to obtain national data on cardiothoracic surgery performed in the relevant countries. Data obtained over a period of 12 months are shown in Tables 1 to 3 and Figures 1 to 4. The authors are representatives of 13 LIC and MIC (including the "BRICS" countries Brazil, Russia, India, China, and South Africa) and 3 HIC. All authors participated in the South-North Dialogue that led to the Cape Town Declaration [1]. Several of the authors were also signatories of the preceding Addis Ababa communiqué [2] and the Cairo Accord [3].

PATIENTS IN NEED

For cardiac surgery, the epidemiological transition that accompanies a country's transformation from low-to high-income status means a gradual shift from young patients with RHD to older patients with degenerative and lifestyle diseases. Whereas the needs for heart surgery are well defined at the endpoint of this transition, they continue to remain undefined for the earlier part of this process.

Patient needs in LIC

Although quantitatively ill defined, it is evident that the two groups of pathologies that still represent a majority of patients in need of cardiac surgery in LIC are congenital heart disease (CHD) and RHD [1-4].

Because the global burden of CHD is believed to be relatively constant [5-9], it seems reasonable to estimate the congenital cardiac surgical needs of LIC on the basis of both global prevalence and local circumstances [9,10]. Screening studies suggested a range of 2.2 to 14 cardiac defects per 1,000 live births [9,11-14]. In the United Kingdom, the countrywide number of actually performed operations for CHD in under-19-year-old patients was 4.5 per 1,000 live births in 2015 [15]. When all age groups were included, there were 8 operations per 1,000 live births both in the United Kingdom [15] and in Germany [16]. Given the significantly lower levels of postnatal diagnosis in LIC and a rational restriction to the simple 70% of indications (atrial septal defects [ASD]; ventricular septal defect [VSD]; tetralogy of Fallot [TFO]; atrio-ventricular septal defect [AVSD]) under those circumstances, 1 per 400 live births would be a conservative

TABLE 2. Relationship between the number of annual cardiac operations and cardiac surgeons per million population expressed in total countrywide numbers and broken down into private and public patients

Open Heart Cases/yr							Cardiac Surgeons		
	% of Cardiac Surgery Patients With Access to Private Sector	Σ (Public/Private)	Public Operations		Private Operations per Million Private Patients	Σ (Public/Private)	Primary Adult/Primary Pediatric	Population/Surgeon Σ (Public)	Surgeon/Million Population
			Σ per Million Public Patients	per Million				Population per Public Surgeon/Private Surgeon	Σ (Public Surgeon per Public Population/Private Surgeon per Private Population)
Mozambique	1	122 (32/90)	7	1	306*	5 (4/1)	4/1	5,800	0.2 (0.1/3.4)
India		205,000 (mostly private)	154	NA	NA	1,500	1,300/200	0.89	1.1
Nigeria	15 [†]	100 (49/51)	0.5	0.3	1.8	11 (10/11)	8/3	18	0.06 (0.07/0.01)
Morocco	53	3,500 (1,400/2,100)	100	88	111	NA	NA	NA	NA
Tunisia	97	3,000 (800/2,200)	272	71	191	60 (20/40)	52/8	0.18 (0.15/0.20)	5.5 (6.7/5.0)
Namibia	25	280 (150/130)	127	88	217	2	2 (both)	1.1	0.9 (0.9/0.9)
Algeria	66	7,300 (4,820/2,480)	178	161	187	96 (75/21)	84/12	0.23	2.3 (2.8/1.5)
Iran	30	42,000 (31,800/10,210)	525	568	425	242 (242/144)	211/31	0.33	3.0
South Africa	17	8,400 (2,450/5,950)	142	50	595	103 (32/71)	90/13	0.57 (1.50/0.14)	1.7 (0.7/7.1)
Cuba	NA	1,969	177		0	82	9	0.14	7.4
China	100	219,000 (212,000/7,000)	158	154	5	3,578 (3,533/45)	3,228/350	0.39	2.6 (2.6/0.03)
Brazil	17	80,081 (66,541/13,540)	374	373	376	2,220	1,725/495	0.1 (0.1/0.02)	10.4 (9.2/43.1)
Russia	NA	71,300	481	481	0	1,196	1,036/160	0.1	8.0 (8.0/0)
Germany [16]	12	103,128 (91,000/12,000)	1,243	1,247	1,200	958		0.09	11.5 (13/96)
Singapore	32	2,500 (1,700)	446	447	444	38	33/5	0.15 (0.11/0.17)	6.6 (5.8/8.9)

Private operations were related to the population on private insurances or that can afford private medicine. Public operations were related to the population that depended on the public sector. Abbreviations as in Table 1.

*Only 300,000 out of 29 million are deemed to be private patients in the country, receiving 90 operations per year. Three hundred and six is therefore, a purely theoretical extrapolation.

[†]Representing the population earning more than 70,000 USD and assumed to be financially capable of affording private cardiac surgery.

TABLE 3. Relative distribution of cardiac surgical cases between the 5 main categories (CABG; valves [in open heart surgery]; congenitals; other [including aortic surgery involving extracorporeal circulation]; and TAVI)

	% CABG		% Valves (% RHD)		% RHD of All Ops	% Congenitals		Other		TAVI/yr Σ
	Public Sector	Private Sector	Public Sector	Private Sector		Public Sector	Private Sector	Public Sector	Private Sector	
Mozambique	0	5	50 (95)	26 (50)	25	19	57	31	12	0
India	25	49	57 (86)	19 (57)	24	13	21	5	11	160
Nigeria	0	17	0	14	7*	26	44	2	0	0
Morocco	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tunisia	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Namibia	15	75	76	15		7	7	2	3	0
Algeria	20	60	60	30	31	15	18	5	2	529
Iran	52		21 (31)		7	8	2	17		120
South Africa	19	55	36 (55)	28 (12)	7	37	11	8	6	170
Cuba	26		24			22		28		0
China	9	18	28 (35)	23 (35)	9	35	42	28	15	900
Brazil	49	49	24 (60)	24 (60)	17	19	19	8	8	>1,000
Russia	50	0	17 (35)	0	6	23	0	10		700
Germany [16]	51		34		<1	6		9		>14,000
Singapore	52	59	25 (15)	21 (?)		9	4	14	16	90

Combined valve and coronary bypass procedures were counted as "valves." Where available, the percentage of valve patients being operated for a rheumatic etiology were listed in brackets.
 Σ , total; CABG, coronary artery bypass graft; NA, not applicable; RHD, rheumatic heart disease; TAVI, transcatheter aortic valve implantation.
 *Valves are not being operated on due to costs of prostheses.

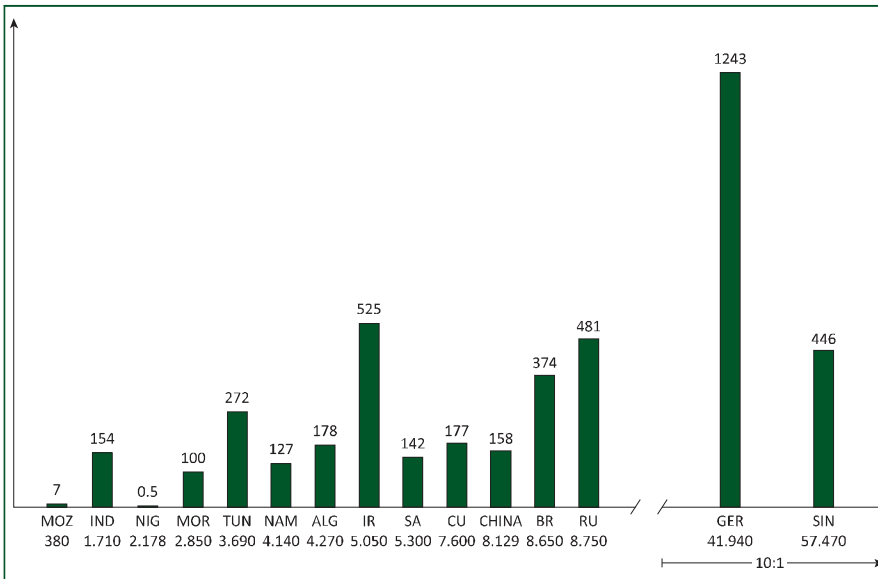


FIGURE 1. Number of open heart operations per million population per year related to the per capita gross domestic product of each country. The upper half of the x-axis has been shortened 10:1 to accommodate 2 high-income countries, Germany and Singapore.

estimate of surgical needs for CHD in LIC. Related to 1 million population, the need for congenital cardiac surgery would therefore be the crude birth rate divided by 0.4, as opposed to 0.125 for the entire spectrum of CHD and all age groups in HIC. As the crude birth rate varies between 43 for the Chad and Burundi and 32 for Rwanda, between 80 and

110 operations may be assumed to be needed for CHD per million population at current birth rates in LIC.

The majority of cardiac surgical needs in adolescence and adulthood in LIC, however, is due to RHD. The most recent Global Burden of Disease study has estimated the burden of RHD at 33 million [17-19], practically the same

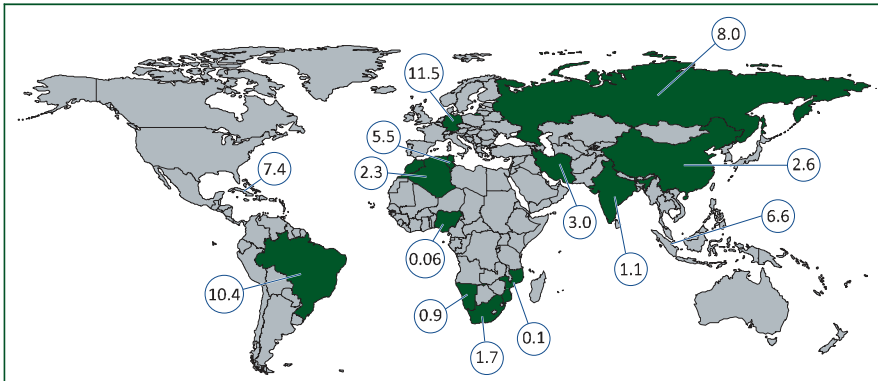


FIGURE 2. World map highlighting the contributing countries. In the circles, the number of cardiac surgeons per million population are depicted for each country.

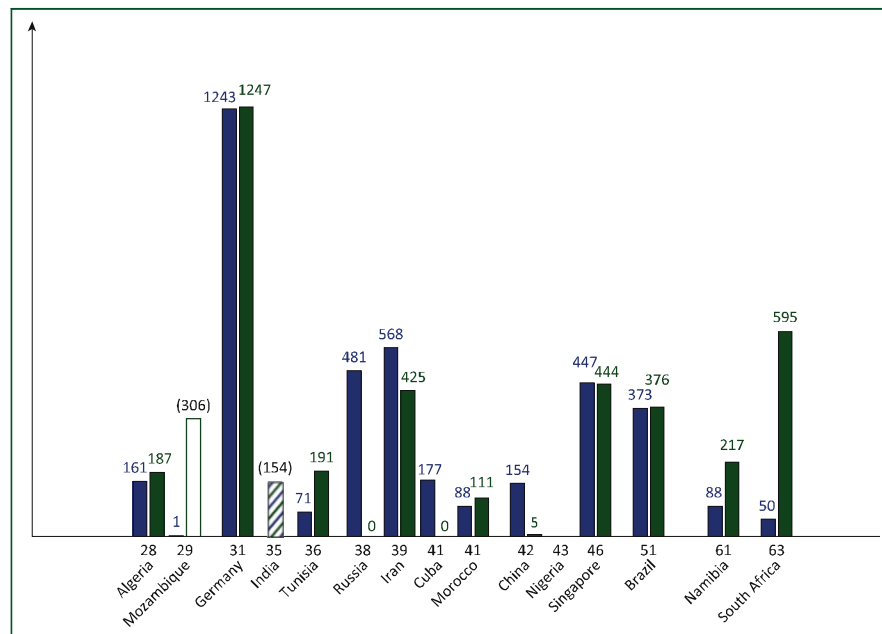


FIGURE 3. Number of open heart operations per million population per year (y-axis) related to the Gini coefficient of each country (x-axis) as a means to describe the level of societal inequality. For each country, the level of cardiac operations offered to public (blue) and private (green) patients was separately depicted.

as the worldwide human immunodeficiency virus infection rate (World Health Organization Global Health Observatory data 2017). The latest studies suggest that 4,440 per million population suffer from nonsilent RHD in endemic areas [17]. Due to the limited availability of cardiac surgery in these regions, and therefore the lack of an endpoint of referral in many endemic areas, few hard data are available from which to extrapolate the proportion of patients with RHD who will eventually need surgery. Several recent studies have highlighted the need for surgery in symptomatic patients, the majority of those presenting at tertiary institutions. Sliwa et al. [20] showed that 22% of patients reach this point within 30 months of becoming symptomatic. Okello et al. [21] and Zhang et al. [22] reported on the presentation of newly diagnosed RHD in Uganda. In this cohort, 72% required valvular surgery at presentation [21,22]. Cannon et al. [23] recently described a very elegant multistate model that confirmed the poor prognosis for those aged 5 to 24 at the time of diagnosis, even in Australia. Of those diagnosed as mild, almost 30% did show progression over 10 years with 11% progressing to severe disease, one-half of these needing surgery. Even more concerning was the fact that 50% of those with severe

RIID at the time of diagnosis required surgery within 2 years and 10% were dead within 6 years of diagnosis [23].

The REMEDY (Global Rheumatic Heart Disease Registry) study enrolled 3,343 patients from LIC and MIC in Africa, India, and Yemen. Symptomatic patients with RIID in need of cardiac surgery were typically young (median age of 28 years), largely unemployed (75% of adults), and often women of childbearing age [24]. With surgery available in only a few of these countries (all upper-middle-income countries), mortality was high, at 17% over the 2-year follow-up with a median age of 29 years of those who died [25]. Other studies reported mean mortalities at an even younger age [26-28].

Estimates of RHD-related heart failure and death rates in areas without surgery could serve as a conservative means of assessing the need for cardiac surgery. With an average age-standardized global RHD-related death rate of 48 per million population per year [17] (87 in endemic areas) and a 3 times higher number of patients with signs of significant cardiac failure [17], a minimum of 150 operations per million population per year may be conservatively assumed. However, with variations of a factor of 3.5 in age-standardized mortality even within the endemic

hot spots of the world [17], this number would be higher, for example, for regions in Oceania (>300 per million), Central Sub-Saharan Africa (>200 per million), or South Asia (>200 per million).

If one attempts an overall assessment of cardiac surgical needs in LIC, a sizable proportion of CHD cases must be assumed to remain silent under the prevailing conditions and, therefore, undiagnosed until they become inoperable. This is in contrast to RHD, where adolescents and young adults are likely to come forward once symptomatic. As a result, an estimated 3 to 4 times more patients with RHD than with CHD are likely to need cardiac surgery in LIC. Therefore, one may conservatively estimate the need for cardiac surgery in LIC to be 300 to 400 per million population within endemic hot spots such as Oceania and 200 to 250 per million in the endemic regions of South Asia and Sub-Saharan Africa.

Patient needs in MIC

As the societies of MIC are at various stages in their transition to urbanization and industrialization, a variable degree of overlap is seen between the cardiac surgical needs of LIC, dominated by RHD, and of HIC with their predominance of degenerative and lifestyle diseases. If the current situation of HIC predicts the endpoint of this transition, the overall incidence of cardiac surgery of 1,300 per million population [16] in a country such as Germany suggests a significantly higher need for cardiac surgery for degenerative and lifestyle diseases than the estimated 200 to 400 cardiac operations per million population even in endemic areas of LIC. As such, the cardiac surgical needs of MIC can be expected to increase slowly by a factor of 4 as they go through the epidemiological and socioeconomic transition from low- to high-income status. During this transition, the two trends are concurrently unfolding in opposite directions. Therefore, a decreasing relative prevalence of a rheumatic etiology of surgical valvular disease in MIC may not only be a reflection of the disappearance of RHD, but also a consequence of a concomitantly growing absolute number of patients with degenerative valve disease. Underscoring this phenomenon, the 2015 share of the worldwide burden of RHD was still 21% for upper MIC such as China (23% of global RHD deaths) compared with the 47% (43% of global RHD deaths) for lower MIC such as India and Pakistan. Together, these 3 MIC composed 70% of worldwide cases [17], countering the perception that RHD is restricted to Sub-Saharan Africa and has been largely eradicated elsewhere.

LACK OF CARDIAC SURGERY

Whereas access to cardiac surgery is largely absent in LIC, it is available but often considerably restricted in many MIC, resulting in >70% of the world population having limited to no access to a service that would otherwise prevent a massive number of deaths and suffering [26].

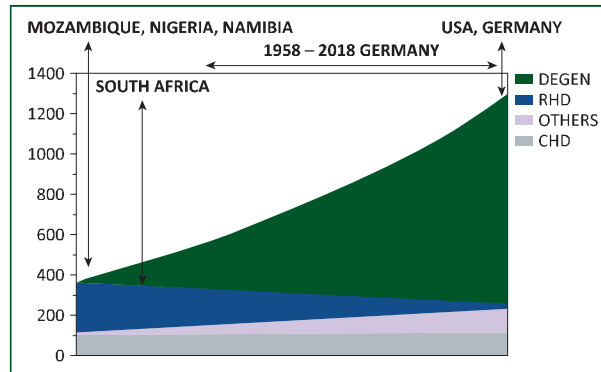


FIGURE 4. Epidemiologic transition reflected in the annual need for cardiac surgery. Whereas the need for surgery for congenital heart disease (gray) is largely constant throughout the world, rheumatic heart disease (blue) gets gradually replaced by degenerative heart disease (green) as a country moves from low-to high-income status over time. In Germany, for instance, this transition was further advanced 60 years ago than in South Africa today. With all their unmet need for cardiac surgery, a low-income developing country has a 4 times lower overall requirement for cardiac surgery than a high-income country does with its massive burden of degenerative heart disease.

In our comparison of 14 countries belonging to 4 income tiers, there was only a weak correlation between the per capita gross domestic product and the provision of cardiac surgery (Figure 1) even if related to health expenditure (Table 1). Iran and South Africa, for instance, spent nearly identical per-capita amounts on health (Table 1), yet Iran performs 525 cardiac operations per million as opposed to 142 in South Africa (Table 2). Similarly, Nigeria's per capita gross domestic product is almost one-third higher than that of India, but India delivers 154 cardiac operations per million as opposed to 0.5 in Nigeria (Figure 1, Tables 1 and 2). Similarly, the number of cardiac surgeons does not necessarily translate into more cardiac operations. Both Brazil and Germany have >10 cardiac surgeons per million population (10.4 per million vs. 11.5 per million) (Figure 2) as opposed to 3 per million in Iran. Yet, Germany provides >3 times more cardiac operations per million population than Brazil and Iran operates 1.5 times more patients with 3.5 times fewer surgeons. Except for the extreme end of the spectrum, the Gini index as an expression of societal inequality does not always correlate with access to cardiac surgery: Algeria with a Gini index of 28 and South Africa with 63 provide similar levels of cardiac surgery (127 per million vs. 142 per million operations). Yet, an access ratio between affluent private patients and indigent patients of 12 in South Africa but only 1.2 in Algeria does correlate with the extremely divergent Gini index between these two countries (Table 1; Figure 3).

Lack of cardiac surgery in LIC

In view of the relatively minimal impact prevention has made in recent years [25], with the death rate not even halved over the last one-quarter of a century [17], surgery will for a long time remain an integral part of the treatment of RHD, because cardiac surgery is eventually the only lifesaving option for the majority of patients with symptomatic disease. Yet, in most of the LIC, it is as good as absent. This lack of access to cardiac surgery is most glaring in Africa. The almost 1 billion people living in Sub-Saharan Africa outside of South Africa have access to only 22 cardiac centers [29]. According to Yankah et al [29] there are 1,222 open heart operations per million population in North America, and 18 per million in Africa, which translates into 1 center per 120,000 people in the United States and 1 center per 33 million people in Africa. It is estimated that 10,000 cardiothoracic surgeons in 6,000 centers globally perform more than 2 million open heart operations per year. Africa has 18 operations per million people versus the global mean of 169 cases per million [29,30].

Although it is widely understood today that local capacity building is the only way to address this problem, humanitarian outreach programs often remain the only source of at least sporadic provision of cardiac surgery. These attempts to help have been criticized in many ways, primarily for being the proverbial “drop in the ocean” at great expense, though undoubtedly many lives have been saved [31–33]. For example, Nigeria hosted their first fly-in mission in 1974. Over the subsequent 3 decades, only 102 further patients underwent cardiac surgery, about one-half of them children, some by visiting teams and some by local surgeons [31,34]. Today's cardiac surgical capacity of this country of 195 million is still almost nonexistent with 0.5 operations per million (Table 2). Nongovernmental organizations have generally now shifted focus toward building long-term partnerships with recipient sites with a vision to eventually develop autonomous local services, because the end goal must be to handle the indigenous pathologies under the socioeconomic circumstances prevailing in the affected countries. Following the same logic, regional outreach missions from locally established cardiac centers are better suited to the needs of underserved regions than similar surgical missions that are based in HIC [26].

Similar to missions from HIC, local capacity building also usually starts with an emphasis on children. A continual high proportion of children being operated on indicates that the overall needs exceed the existing capacity resulting in prioritization of the most vulnerable. The Aswan Heart Centre of the Chain of Hope, established in 2009 [26], is an example where >1,000 open heart procedures are now being performed per annum, of which more than one-half are still children.

Capacity gap of cardiac surgery in MIC

Although the first open heart operations on cardiopulmonary bypass were performed in Brazil in 1956, in China in

X'ian in 1958 (by 1964, 20 hospitals were doing open heart surgery), in South Africa by Christiaan Barnard in 1958, and in Mumbai in 1961, population growth and epidemiological transformations continue to outpace the rollout of cardiac surgical capacity.

With an epidemiological transition that has as endpoint a several-fold higher need for cardiac surgery than existed at the starting point, the accuracy of the overall need estimate of MIC for cardiac surgery depends on the ability to determine the stage of both the epidemiological and the socioeconomic transition. Two feedback parameters appear particularly suited for this assessment: the percentage of isolated coronary bypass graft operations (CABG) reflecting the epidemiological transition (expected to increase from low numbers [e.g., 9% in China] to more than one-half of all procedures [Russia 50%, Brazil 53%, Singapore 52%, and Germany 51%]), and the overall number of cardiac operations performed per million population as a reflection of the socioeconomic transition (e.g., 0.5 per million in Nigeria vs. 1,243 per million in Germany). Mozambique, for instance, has a <5% CABG rate, with 8 cardiac operations per million population (Table 1) and as such clearly represents a very early phase of the transition typical for a LIC. China's national average of 9% for CABG at 158 operations per million indicate a later but still relatively early stage of both transitions. However, national data may conceal the concurrence of parallel societies within a country or societal differences between countries. In China, for instance, the 27% CABG share at big urban centers such as Fuwai highlights the urban-rural gradient. In all MIC, cardiac surgery is often predominantly located in metropolitan urban areas and their immediate surroundings. Large centers such as Fuwai in Beijing with 15,000 open heart cases per year, Bakoulev in Moscow with >5,000 per year or the All India Institute for Medical Sciences in Delhi push up the national numbers, thereby making undersupply in nonmetropolitan areas less obvious. At the end of 2017, China had 723 cardiac centers (0.5 per million population or 1.9 million population per center) performing 219,000 open heart operations (158 per million population) (Tables 1 and 2). If equally distributed, each center would have performed 303 cases per year compared with 1,100 per center per year in Germany. This situation is further aggravated by the fact that 404 of the 723 hospitals (53%) performed <100 operations per year and 525 hospitals (79%) <300. As such, 75% of all patients are largely operated in the 21% urban hospitals performing >300 cases per year. It also means that the 42% of the population living in rural areas get only 25% of all cardiac operations often in units performing <100 operations per year. Similar to China, most of the centers performing open heart surgery in India are located in the major cities and patients often have to travel long distances for treatment. At the same time, whereas there are 31 mostly metropolitan heart transplant centers (in 2016 performing a total of 107 transplants), there are still extremely underserved rural regions. States such as

Bihar, Mizoram, Sikkim, Manipur, Arunachal Pradesh, Tripura, Nagaland, Meghalaya, Rajasthan, Himachal Pradesh, and Uttarakhand, which account for one-quarter of India with 15% of its population, have hardly any access to cardiac surgery. Similarly, the densely populated, highly urbanized South/South-East of Brazil has amassed a disproportional share of the 337 cardiac centers of the country. In Russia, before it was re-established as a separate state in 1991, the leading heart centers in the country were in Moscow, Kiev, Vilnius, Leningrad (now St. Petersburg), Novosibirsk, and Gorkey (now Nizhniy Novgorod). Since then, many new heart centers were opened throughout the country adding up to a total of 119 in 2017. Yet, there is still a distinct undersupply outside the metropolitan centers. Today, the least compromised situation is still in the Central Federal district. Then comes the Pri Volga District and Siberia. The worst conditions prevail in the North Caucasus and the Far Eastern District.

In all MIC, 1 mitigating factor in this unequal access to cardiac surgery lies in the lower cardiac surgical needs of rural populations due to their slower epidemiological transition evident from a prevailing bias of RHD over lifestyle diseases. For instance, a 74% versus 57% rate of urbanization and a 50% versus 9% CABG rate in Russia and China, respectively, suggest that in relative terms, the 3 times lower per capita delivery of heart surgery in China (154 per million population) compared with Russia (481 per million population) is not reflecting the full picture. Yet, although less pronounced, the overall Chinese need for cardiac surgery can still be expected to be lower than that of Russia. Other reasons for hidden discrepancies may be rooted in demographics. Whereas on the surface, Russia's 50% CABG rate and 481 per million operations match Singapore's 52% CABG rate and 446 operations/million (Table 2), the one (Russia's) largely represents a post-transition society with a high degree of degenerative and lifestyle diseases with limited access to cardiac surgery, and the other (Singapore's) represent a younger population less affected by degenerative diseases with full access to cardiac surgery. Similarly, although Iran's urbanization is high (74%) as is its CABG rate (52%), a coexisting prevalence of 31% RHD in all valve patients suggests a mid-stage of epidemiological transition. As such, the current level of 525 per million cardiac operations (the highest of all MIC) may in relative terms cover an even higher proportion of patients in need. At the end of the spectrum stand HIC such as Germany with 51% CABG and 1,257 operations per million [16], reflecting the patient needs of an aging, affluent, 76% urbanized population with full access to cardiac surgery (Tables 1–3).

Whereas the epidemiological transition follows socio-economic circumstances, the role of the private practice of cardiac surgery crucially differs from country to country not necessarily reflecting the Gini coefficient of societal inequality. At the extreme end is South Africa, where those 17% of the population who have access to private medicine receive 595 cardiac operations per million, whereas the

83% of the population who depend on public medicine only receive 50 operations per million per year. Alternatively expressed, 1 private hospital cares for 300,000 cardiac surgical patients who have medical insurance (with 7.1 cardiac surgeons per million) as opposed to 6.1 million patients per center who depend on the public sector (with 0.7 cardiac surgeons per million). In the Maghreb countries, in contrast, 72% of the population have access to private medicine but because private facilities are reimbursed by procedure-related lump sum payments, the more high-risk private patients are denied surgery and end up receiving care on the public side. In this regard, the two extremes are Russia and Cuba, where no private cardiac surgery exists and Germany, where the entire population has access to privately owned cardiac hospitals (but not to the "private" services all hospitals including the publicly owned ones offer). Thus, while private institutions and surgeons are totally separate in South Africa, all cardiac hospitals in Germany offer stepped up services to those 12% of the population who have a private top-up insurance (baseline costs are covered by public insurances for all). Legally similar (but increasingly showing signs of financial strain), the social service in Brazil provides every citizen with free health care. The state insurance system (Unified Health System) covers 83% of the population in 100% of hospitals. Similar to Germany, all cardiac hospitals treat both private and public patients, except for the 5% of hospitals that are purely public. As such, private patients who have either a private insurance (10%) or pay out of pocket (7%) have access to 95% of cardiac centers. In Iran, most doctors other than the professors (who are full-timers at the University Hospitals) work both in public and in private. A vast majority of all patients are treated almost for free (10% in Social Security hospitals; 60% at university hospitals, and 10% at hospitals belonging to government organizations such as the military). The remaining 20% are private patients treated in private hospitals that were founded by doctors. In China, private cardiovascular surgery has just begun to emerge. Theoretically, all of the 3,578 cardiovascular surgeons are allowed to work at multiple places (e.g., public and private). The government's medical insurance largely covers 50% of the medical cost during any admission even in private hospitals. In return, all government hospitals may treat "private patients" who pay modestly more. The profit of the private hospitals is mainly from the medical consumables because private hospitals can independently negotiate the price of consumables. All together, there are only 5 major private hospitals in China dedicated to cardiovascular surgery operating on 3% of all patients. In India, even in government hospitals, patients still need to contribute 1,000 to 2,000 USD to a cardiac operation as opposed to 3,000 to 5,000 USD in a private facility. Of all cardiac hospitals, <10% are public. Government or state employees get their main expenditure reimbursed if they get operated on in a government-endorsed private hospital. Some government schemes are in place allowing indigent

patients and school children to be taken care of in private hospitals. Alternatively, private hospitals that were subsidized by the state with free land have to provide a certain percentage of service free to the poor. With the Narayana Health Care facilities, a low-cost private system emerged that entered collective insurance agreements for instance with agricultural cooperatives. For literally pennies a month, enrollees receive comprehensive coverage for all surgeries.

SUMMARY

HIC are past their epidemiological transition and have developed well-established cardiac surgical services that largely cover their population's needs. As such, their known prevalence of adult and pediatric cardiac operations as well as their patterns of underlying pathologies can be seen as a contemporary saturation point of an industrialized society. LIC, in contrast, are largely in a pre-epidemiological transition phase, and as such, needs are very different from those of industrialized countries. Although it is an acknowledged fact that the two main pathologies requiring cardiac surgery in LIC are congenital cardiac defects and RHD, estimates have been vague and largely based on echocardiographic screening studies [35]. Recent global and regional epidemiological studies have, for the first time, correlated the prevalence of silent rheumatic valvular disease with that of cardiac failure and death caused by the disease allowing conservative estimates of the need for cardiac surgery for RIID. Although these indirect deductions will remain estimates until such time when well-established cardiac services provide firm data, they for the first time allow an approximate assessment of two core questions: how many cardiac operations should one expect to be needed in an LIC per million population and how much do the needs for cardiac surgery differ between a pre-transition LIC and a post-transition HIC. Conservatively narrowing the range to 100 to 300 operations per million population for LIC highlighted the fact that the gradual disappearance of rheumatic heart RHD with affluence and its replacement with degenerative/lifestyle diseases will translate into a 4 to 5 times higher need for cardiac surgery once the epidemiological transition has been concluded (Figure 4). This assumes today's circumstances continue to apply and does not take lifestyle changes and future preventive pharmacotherapies and other strategies into account. An estimated ratio of 3 to 5:1 of RHD to CHD also allows investigators to assign a rough numeric value to the often less visible needs of rheumatic patients in LIC against the background of children's needs. Last but not least, MIC have made impressive strides toward provision of cardiac surgical services in the recent past. The simultaneous presence of RHD and degenerative/lifestyle diseases in these countries allows at least an informed guesstimate of where the cardiac surgical needs of the population on the epidemiological transition scale from 100 to 1,200 per million may lie. Our multi-author attempt to define the

national status of open heart surgery in 1 LIC, 4 lower-middle income countries, 8 upper-middle-income countries, and 2 HIC does not claim to accurately represent the situation in all comparable countries. It does, however, allow a very critical comparison of key parameters based on major representatives in each group. In the short run it may provide guidance for governments and nongovernmental organizations in LIC while also helping to predict the medium-term to long-term developments in MIC. This study was partially supported by the South African National Research Foundation (NRF) through the grant for rated scientists.

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