ORIGINAL RESEARCH

The presence and availability of essential diagnostics in Malawian district and central hospitals: A secondary analysis of a nationwide survey of musculoskeletal trauma care capacity

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Abstract

Background
Diagnostics are foundational to effective health systems but remain widely unavailable worldwide, especially in low-income countries like Malawi. To achieve health equity in Malawi, it is necessary to assess the availability of essential diagnostics.

Methods
We analysed data collected during a nationwide survey of musculoskeletal trauma care capacity. We analysed the presence, availability, and reasons for unavailability of laboratory testing, vital signs monitoring, electrocardiography, and diagnostic radiology at all 25 district hospitals and 4 central hospitals in Malawi. We used geospatial models to estimate the proportion of the Malawian population with 1-hour and 2-hour access to these resources. Taking 1-hour access to most accurately represent geospatial coverage in the Malawian context, a hypothetical intervention was designed whereby diagnostic capacity improvement would be prioritized at selected hospitals to cover at least 75% of Malawians nationwide.

Results
Twelve of 29 hospitals had basic laboratory testing available when needed, covering an estimated 58% of Malawians with 1-hour access and 95% with 2-hour access. Vital signs monitoring was available when needed at 18 hospitals, covering an estimated 74% of Malawians with 1-hour access and 97% with 2-hour access. Six hospitals reported that electrocardiography was available when needed, covering an estimated 49% of Malawians with 1-hour access and 91% with 2-hour access. Four hospitals had x-ray capacity of adequate quality to make accurate diagnoses when needed, covering an estimated 39% of Malawians with 1-hour access and 86% with 2-hour access. Broken machinery, inadequate supplies, and inadequate staff training were common reasons for resource unavailability.

Conclusions
Essential diagnostics were found to be unavailable for many Malawians. By prioritizing capacity improvements for all 4 central hospitals and 11 district hospitals, over three-quarters of Malawians could have 1-hour access to laboratory testing, vital signs monitoring, electrocardiography, and diagnostic x-ray. These capacity improvements are essential to meet the needs of a growing population, especially in the context of the current COVID-19 pandemic.

Keywords: trauma, capacity, infrastructure, human resources, essential resources, diagnostics, COVID-19, health systems strengthening, pandemic preparedness, Malawi

Introduction

Health systems rely on accurate diagnostics.[1] Vital signs monitoring, laboratory testing, histopathology services, and radiology services are essential to all medical and surgical specialities.[2],[3] However, essential diagnostics are often unavailable in low-income countries, and this unavailability contributes to inadequate treatment and poor health outcomes.[4]-[6] Health systems diagnostic capacity building is cost-effective and necessary to achieve health equity.[4]

About 84% of Malawi's 18 million people live in rural areas,[7] and about 60% of healthcare services are provided by public hospitals organized into 3 levels: (1) rural health centres that provide basic medical services and no surgical care, (2) district hospitals that provide nonspecialized medical and surgical care, and (3) central hospitals that offer specialized medical and surgical care.[8],[9] Foreign donors cover 52% of current health expenditures.[10]

HIV/AIDS, lower respiratory infections, tuberculosis, diarrhoeal diseases, and malaria cause about 40% of deaths in Malawi.[11] Ischaemic heart disease and stroke cause about 9% of deaths and are increasingly prevalent.[11]-[13] Malawi has the world's fourth highest road injury mortality rate at 34.2 per 100 000 people.[14] One-third of Malawians live with an untreated surgical condition.[15] Injuries are increasingly common, and Malawi's health system lacks essential capacity to manage these injuries.[8],[16]-[19] The current COVID-19 pandemic has also underscored the need to build health system capacity, including diagnostics.[20],[21]

A detailed understanding of Malawi's health system capacity is essential as a baseline for any health strategy to meet the population's basic health needs. We sought to examine the presence and availability of diagnostics—laboratory testing, vital signs monitoring, electrocardiography, and diagnostic radiology—throughout Malawi. We hope these findings may guide efforts to improve patient care.

Methods

We previously conducted a nationwide assessment of musculoskeletal trauma care capacity in Malawian public hospitals. Between 29 May and 15 June 2018, we assessed the initial evaluation, definitive treatment, aftercare, and rehabilitation of femoral shaft fractures as a representative injury.[8] We surveyed orthopaedic providers at all 25 district hospitals and 4 central hospitals in Malawi (Figure 1). For 51 items reflecting infrastructure, human resource capacity, and material resource capacity, we assessed whether each item was routinely present at each hospital, as well as each item's actual availability when needed by staff members in the week before survey completion. We queried reasons for item unavailability. Survey responses were validated by simultaneous, independent on-site assessments of 25% of hospitals.[8]

For this study, we performed a secondary analysis of the availability of the following diagnostic elements: (1) laboratory testing, including basic chemistry panel, urea and electrolytes, and full blood count; (2) supplies for vital signs monitoring, including thermometers, adult blood pressure cuffs, and pulse oximeters; (3) electrocardiography; and (4) diagnostic radiology services, including x-ray and computed tomography (CT). For each item, we assessed its physical presence in the hospital, its availability when needed in the 7 days before survey completion, and reasons for unavailability at all district and central hospitals. We counted the number of district and central hospitals that reported each item being present and then those that counted each item being available when needed. We calculated the frequency that each item was reported as present and available at district and central hospitals. Although the presence of ultrasonography was assessed in the original capacity survey, its availability was only assessed for diagnosis of deep vein thrombosis. Ultrasonography capacity was not assessed in this secondary analysis because there was a lack of broadly relevant data on its availability,

To estimate geospatial access to resources, we listed hospitals where (1) basic chemistry panel and full blood count capacity were available when needed; (2) supplies for vital signs monitoring—including thermometers, adult blood pressure cuffs, and pulse oximeters—were available when

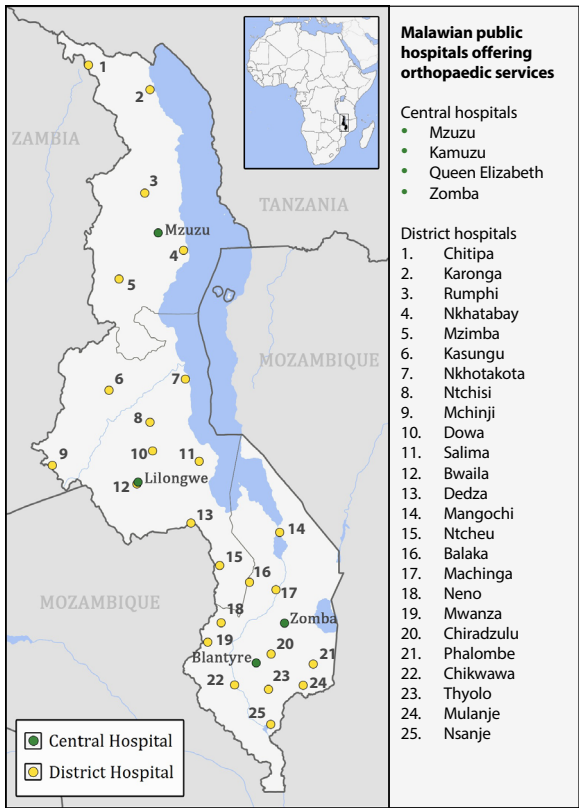

Figure 1. Locations of all government district and central hospitals in Malawi

Each district hospital is represented by a yellow dot, numbered, and labelled in the righthand panel. Each central hospital is represented by a green dot and labelled. Original maps were sourced from USGS National Map Viewer (http://viewer.nationalmap.gov/viewer/) and Maps at the CIA (https://www.cia.gov/library/publications/the-world-factbook/index.html). The figure is similar but not identical to the original images and is for illustrative purposes only.

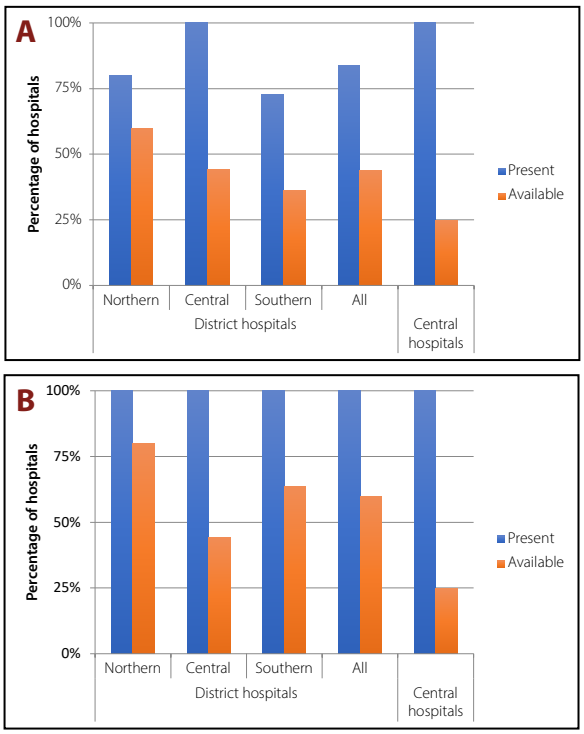

Figure 2. The presence and availability of (A) basic chemistry panel/urea and electrolytes and (B) full blood count in Malawian district and central hospitals

District hospitals were subdivided by geopolitical region: Northern, Central, and Southern.

needed; (3) electrocardiography was available when needed; and (4) x-ray capacity of adequate quality to make accurate diagnoses was available when needed. These hospitals were geocoded and analysed on Redivis (Redivis Inc., Mountain View, CA, USA).[22] Rather than calculate straight-line distances, Redivis uses road location, type, and mean speed to estimate travel time between 2 points. Estimated travel time (ETT) does not represent actual travel times, the calculations of which depend on many other factors, including mode of transportation and road conditions. However, ETT can serve as a standardized, practical proxy for the distance between 2 points (with consideration of road location and quality). We generated coverage maps to estimate the proportion of the Malawian population living within an ETT of 60 minutes (1-hour access) and 120 minutes (2-hour access) from hospitals in each of the 4 lists.

Other investigators have used the 2-hour access benchmark to model geospatial coverage, with 2 hours representing the time between bleeding onset and death without medical intervention.[23],[24] However, while this threshold does represent ideal access to health facilities—with the presumption that a private vehicle or ambulance is used for transportation—it fails to account for the myriad transportation challenges that patients may face in reaching hospital. An ETT threshold of 120 minutes may overestimate access in Malawi, where animal-drawn carts, public transport, and bicycles are common means of getting to hospital, and inadequate funds for transportation plays a key role in preventing patients from seeking timely care.[15],[25] More than 30% of adult patients with fractures were found to have presented late to 4 public hospitals in Malawi.[26] Patients with an ETT from home to hospital ≥20 minutes had a 36% increased risk of delayed presentation, and fewer than 10% of patients who presented at all had an ETT >60 minutes. We, therefore, regarded 1-hour access (ETT <60 minutes) to more accurately represent satisfactory coverage in the Malawian context.

We repeated our models for geospatial access to laboratory testing, vital signs monitoring, electrocardiography, and x-ray after a hypothetical intervention wherein each of these diagnostic capabilities were improved at selected hospitals. The intervention goal was to expand the availability of each of these diagnostic capabilities to the fewest number of hospitals to achieve minimum coverage of three-quarters of Malawians with 1-hour access nationwide. Applying principles of egalitarianism and utilitarianism,[27] as well as data from the 2018 Malawi Population and Housing Census,[7] we prioritized hospitals for capacity improvement according to the following criteria:

1. All 4 central hospitals were prioritized equally (egalitarianism).
2. At least 1 district hospital was prioritized in each geopolitical region (Northern, Central, Southern) (egalitarianism).
3. Priority was given to geopolitical regions and districts with the largest populations or highest population densities (utilitarianism).

Results of this hypothetical intervention informed our recommendations to improve diagnostic capacity nationwide.

Analyses were performed with Excel (Microsoft Corp., Redmond, WA, USA) and SAS 9.4 (SAS Institute, Cary, NC, USA). The College of Medicine Research and Ethics Committee (COMREC P.02/18/2360), in Malawi, and the Institutional Review Board at Brigham and Women's Hospital, in the United States, granted ethical approval.

Results

Laboratory testing

Basic chemistry panel capacity was present at 21 of 25 district hospitals (84%), and it was available when needed in the week before survey completion at 11 of 25 district hospitals (44%). Full blood count capacity was present at 25 of 25 district hospitals (100%) and available when needed at 15 of 25 district hospitals (60%). The most common reason for laboratory unavailability at district hospitals was that necessary equipment, reagents, or other supplies were out of stock or insufficient in number (7 of 12 district hospitals). Other reasons included broken machinery awaiting repairs (3 of 12) and no electricity (1 of 12). Two district hospitals reported outsourcing laboratory testing to nongovernmental organizations: Médecins sans Frontières and Partners in Health.

Basic chemistry panel and full blood count capacity were present at all 4 central hospitals (100%) and available when needed at 1 of the 4 central hospitals (25%). Laboratory tests

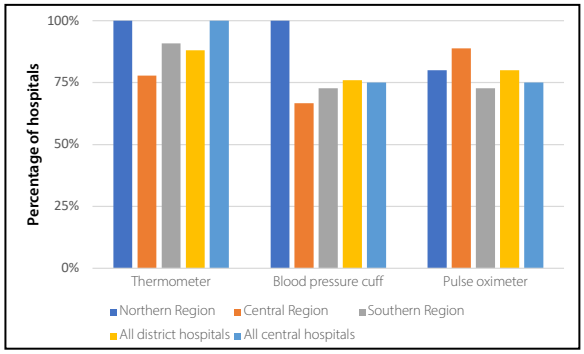

Figure 3. The availability of vital signs monitoring at Malawian district and central hospitals

The tools for vital signs monitoring that were examined in this study were thermometers, blood pressure cuffs, and pulse oximeters. District hospitals were subdivided by geopolitical region: Northern, Central, and Southern.

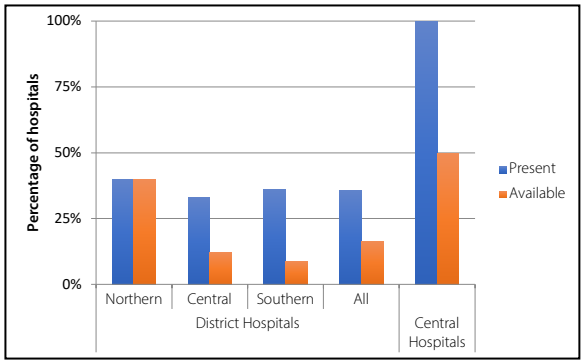

Figure 4. The presence and availability of electrocardiography in Malawian district and central hospitals

District hospitals were subdivided by geopolitical region: Northern, Central, and Southern.

were unavailable when needed because of broken machinery awaiting repairs (1 of 3 central hospitals), as well as necessary equipment, reagents, or other supplies being out of stock or insufficient in number (3 of 3) (Figure 2).

Vital signs

Thermometers were present at 24 of 25 district hospitals (96%) and available when needed in the week before survey completion at 22 of 25 district hospitals (88%). They were unavailable when in use elsewhere or could not be located when needed. Adult blood pressure cuffs were present at all 25 district hospitals (100%) and available at 19 of 25 district hospitals (76%). They were unavailable because they were broken and awaiting repairs (3 of 6 district hospitals) or in use elsewhere (3 of 6). Pulse oximeters were present at all district hospitals (100%) and available at 20 of 25 district hospitals (80%). They were unavailable when needed because they were in use elsewhere (4 of 5 district hospitals) or because they could not be located (1 of 5).

Thermometers were present and available when needed at all central hospitals (100%). Blood pressure cuffs were present at all central hospitals (100%) and available when needed at 3 of the 4 facilities (75%). One central hospital reported that their blood pressure cuffs were broken. Pulse oximetry was available at all 4 central hospitals and available when needed at 3 of the hospitals (75%). At 1 central hospital, a pulse oximeter could not be located or was in use elsewhere when needed (Figure 3).

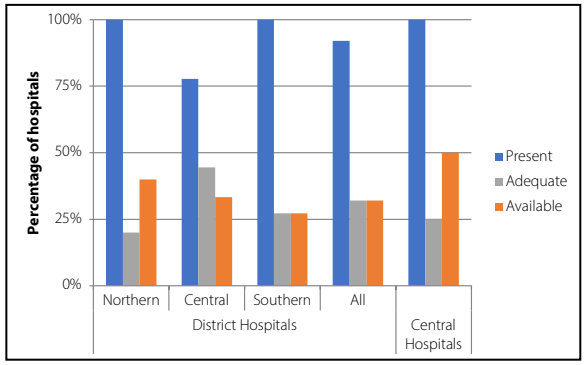

Figure 5. The presence, adequacy, and availability of staff and machines to perform x-ray at Malawian district and central hospitals.

District hospitals were subdivided by geopolitical region: Northern, Central, and Southern.

Electrocardiography

Electrocardiographs were present at 9 of 25 district hospitals (36%) and available when needed in the week before survey completion at 4 of 24 reporting district hospitals (17%). Electrocardiographs were unavailable when needed because necessary equipment or other supplies were out of stock or insufficient in number (2 of 5 district hospitals), they were in use elsewhere (2 of 5), broken and awaiting repairs (1 of 5), or staff members were inadequately trained to use them (1 of 5). Electrocardiographs were present at all 4 central hospitals and available when needed at 2 of the 4 facilities (50%). Two central hospitals reported unavailability when the electrocardiographs were being used elsewhere (Figure 4).

Diagnostic radiology

X-ray machines and necessary staff were present at 23 of 25 district hospitals (92%). Eight of the 23 district hospitals with x-ray capacity (35%) reported that x-rays were consistently of adequate quality to make accurate diagnoses. In the week before survey completion, x-ray capacity was available when needed at 8 of 25 district hospitals (32%). Reasons for unavailability in district hospitals included that the x-ray machine was broken and awaiting repairs (10 of 18 district hospitals)—for as long as 5 years (1 of 18) with insufficient funds to repair or procure new machinery (2 of 18); and that necessary equipment or other supplies were out of stock or insufficient in number (4 of 18). Frequent electricity blackouts or power surges (4 of 18) rendered some x-ray machines temporarily or permanently unusable.

All 4 central hospitals had staff and machines to perform x-ray examinations (100%). One of the 4 central hospitals

Table. Priorities to improve national diagnostics capacity in Malawi

Hospital	Laboratory testing[a]	Vital signs monitoring[b]	ECG[c]	X-ray[d]
Central hospitals				
Mzuzu	●	●	○	○
Kamuzu	○	●	●	○
Queen Elizabeth	○	○	●	○
Zomba	○	●	○	○
District hospitals				
Northern Region				
Karonga	○	●	–	●
Mzimba	●	●	○	○
Rumphi	–	○	–	–
Central Region				
Dedza	○	●	–	○
Dowa	●	●	○	●
Kasungu	○	●	○	○
Mchinji	–	○	–	–
Ntcheu	●	○	–	●
Southern Region				
Machinga	○	○	○	○
Mangochi	○	○	○	○
Thyolo	○	○	○	○

ECG, electrocargiography

The goal of capacity improvement was to achieve a minimum coverage of 75% of Malawians nationwide with 1-hour access to each diagnostic capability. Hospitals were prioritized utilizing principles of egalitarianism and utilitarianism, along with population and population density data from the 2018 Malawi Population and Housing Census.[7] [a]Basic chemistry panel/urea and electrolytes and full blood count available when needed. [b]Vital signs monitoring available when needed (thermometers, blood pressure cuffs, and pulse oximeters). [c]Electrocardiography available when needed. [d]X-ray of adequate quality to safely treat patients available when needed. (●) denotes capacity had been met at the time of the capacity assessment; (○) denotes capacity had not been met and should be prioritized; (–) denotes capacity had not been met. Hospitals in bold would have all four diagnostic capabilities available after the hypothetical intervention.

(25%) reported that x-rays were consistently of adequate quality to diagnose patients accurately. X-ray services were available when needed at 2 of the 4 central hospitals (50%). Reasons for unavailability included that the x-ray machine was broken and awaiting repairs (1 of 2 central hospitals) and that staff members were unavailable at night or on weekends (1 of 2) (Figure 5).

No district hospitals had CT scanners. A CT scanner was present and available when needed at 1 central hospital, where it provided images of adequate quality to safely treat patients. Another central hospital reported that a CT scanner had been in storage for 5 to 6 years and was yet to be installed.

Geospatial access to resources

An estimated 84% of Malawians had 1-hour access, and 99% had 2-hour access, to government-run district or central hospitals nationwide (Figure 6A). Twelve of these hospitals had laboratory testing available when needed, covering an estimated 58% of Malawians with 1-hour access and 95% with 2-hour access (Figure 6B). Vital signs monitoring was available when needed at 18 hospitals, covering an estimated 74% of Malawians with 1-hour access and 97% with 2-hour access (Figure 6C). Six hospitals reported availability of electrocardiography when needed, covering an estimated 49% of Malawians with 1-hour access and 91% with 2-hour access (Figure 6D). An estimated 39% of Malawians had 1-hour access, and 86% had 2-hour access, to 1 of the 4 public hospitals where x-ray was reportedly available when needed and of adequate quality to make accurate diagnoses (Figure 6E).

Recommendations for intervention

No district or central hospital in Malawi had all 4 diagnostic capabilities available at the time of survey completion. Diagnostic capacity improvements should be prioritized at all 4 central hospitals and 11 district hospitals—3 in the Northern Region, 5 in the Central Region, and 3 in the Southern Region. After this hypothetical intervention, all 4 diagnostic capabilities would be available when needed at every central hospital and 6 district hospitals (Table). Twenty-two per cent more Malawians would gain 1-hour access to laboratory testing if its availability were improved in 3 of the 4 central hospitals and the following district hospitals: Dedza, Karonga, Kasungu, Machinga, Mangochi, and Thyolo. This would increase coverage to an estimated 80% of Malawians with 1-hour access and 99% with 2-hour access (Figure 7A). By increasing the number of thermometers, blood pressure cuffs, and pulse oximeters at Blantyre's Queen Elizabeth Central Hospital—and the district hospitals in Machinga, Mangochi, Mchinji, Ntcheu, Rumphi, and Thyolo—an additional 8% of Malawians would gain 1-hour access to vital signs monitoring, increasing estimated coverage to 82% with 1-hour access and 99% with 2-hour access (Figure 7B).

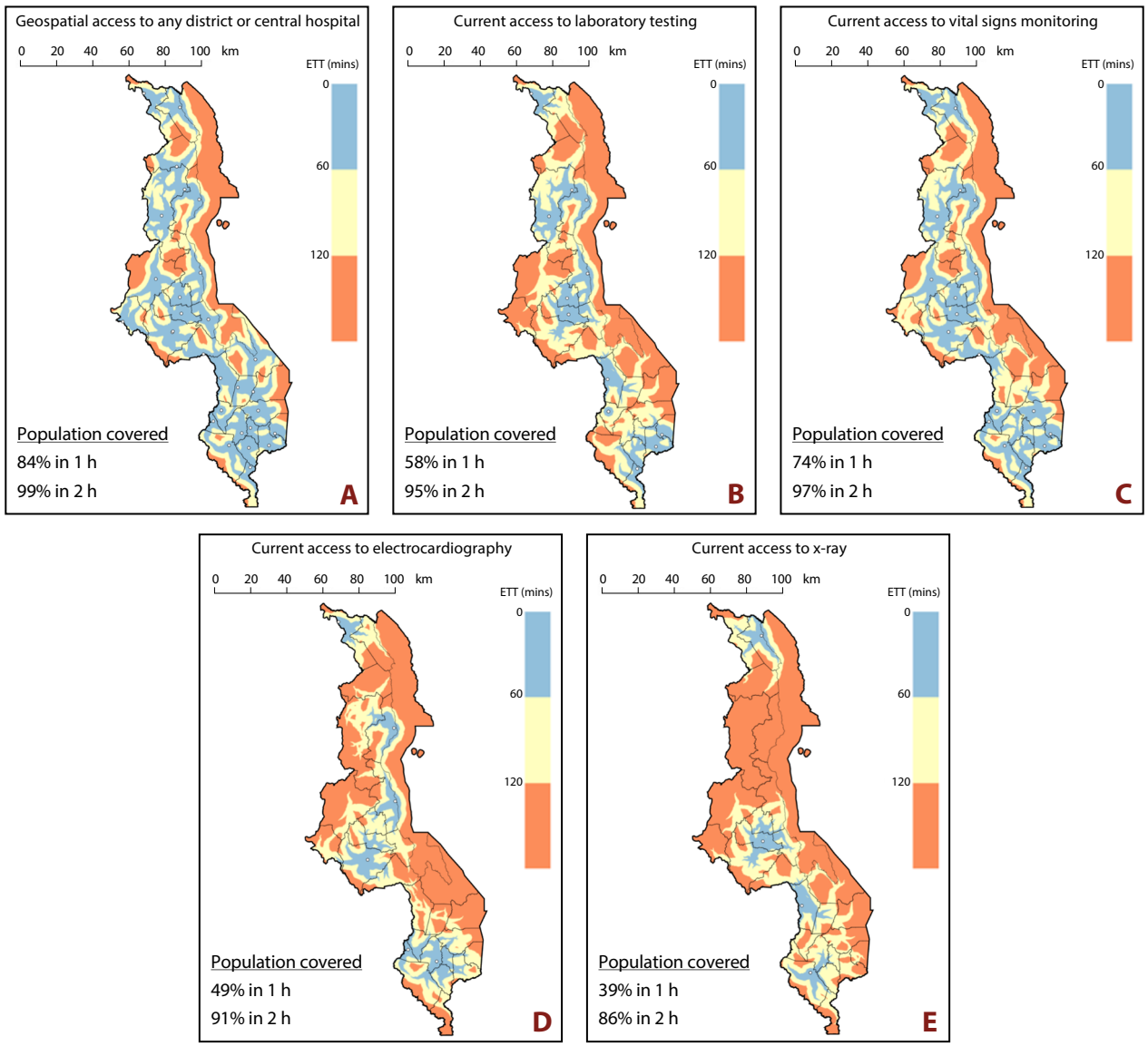

Figure 6. Geospatial access to (A) any district or central hospital, (B) laboratory testing, (C) vital signs monitoring, (D) electrocardiography, and (E) diagnostic x-ray

The estimated percentages of the Malawian population living within estimated travel times (ETTs) of 60 minutes and 120 minutes from the resources in question are displayed in the bottom left of each frame. Coverage maps were calculated and visualized using Redivis (Redivis Inc., Mountain View, CA, USA). Original images have been formatted for stylistic purposes, though scale and calculations have been preserved.

Electrocardiograph machines and equipment are needed to improve access to electrocardiography. Priority should be given to Mzuzu and Zomba central hospitals and the following district hospitals: Dowa, Kasungu, Machinga, Mangochi, Mzimba, and Thyolo. Electrocardiography would become available to 27% more of the Malawian population, increasing estimated coverage to 76% with 1-hour access and 99% with 2-hour access (Figure 7C). Improvement of diagnostic x-ray capabilities should be prioritized at all 4 central hospitals and the following district hospitals: Dedza, Kasungu, Machinga, Mangochi, Mzimba, and Thyolo. This would allow 36% more Malawians to gain access to x-ray, increasing estimated coverage to 75% with 1-hour access and 98% with 2-hour access (Figure 7D).

Discussion

Within an ETT <60 minutes, laboratory testing, electrocardiography, and diagnostic x-ray were unavailable to 42%, 51%, and 61% of Malawians, respectively. These tools are essential for diagnosing and monitoring patients with a wide variety of medical and surgical conditions, ranging from renal failure, to myocardial infarction, to bowel obstruction.[28]-[30] A lack of essential diagnostic tools can delay treatment or result in presumptive treatment initiated without the support of diagnostics, which can negatively affect health outcomes and waste limited resources.[4] In Malawi, broken machinery, inadequate supplies, and inadequate staff training were common reasons for unavailability of these essential diagnostics. To strengthen the health system, these limitations should be addressed.

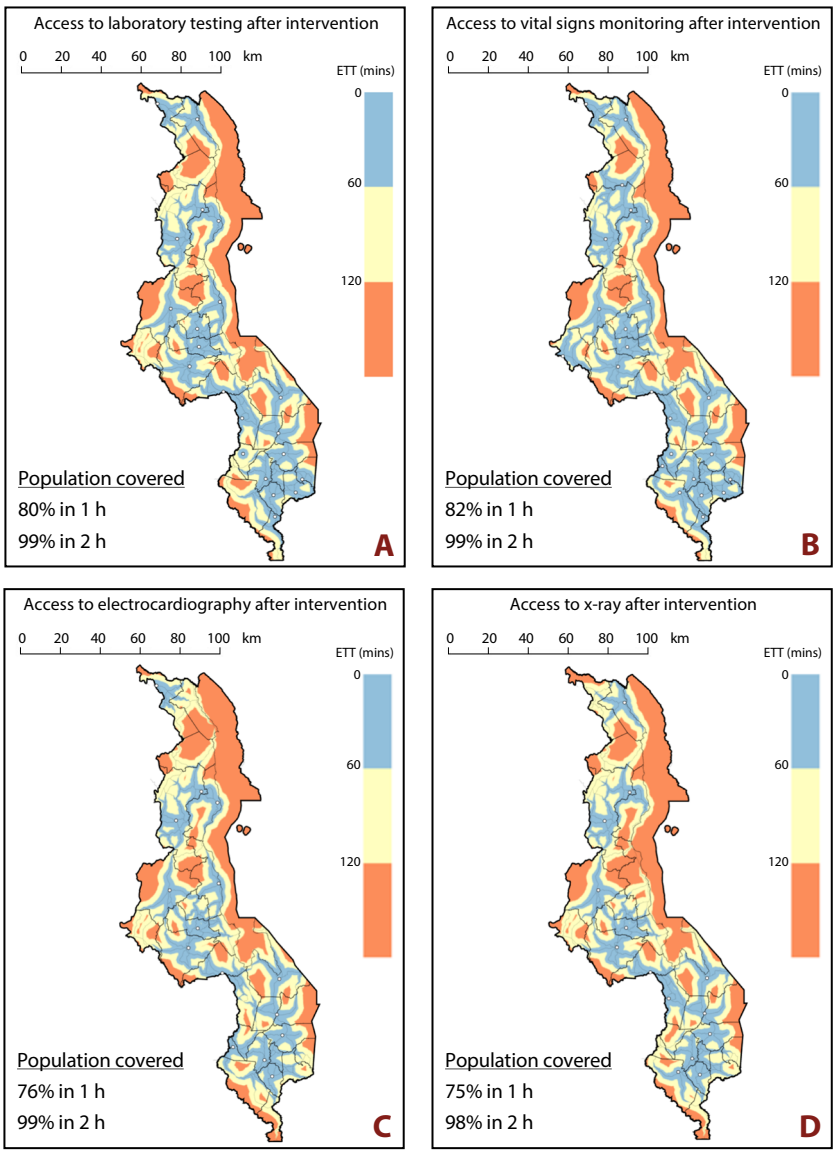

Figure 7. Geospatial access (after "intervention") to (A) laboratory testing, (B) vital signs monitoring, (C) electrocardiography, and (D) diagnostic x-ray

The hypothetical "intervention" involved improving diagnostic capacity at selected hospitals, using principles of egalitarianism and utilitarianism to set priorities. The estimated percentages of the Malawian population living within estimated travel times (ETTs) of 60 minutes and 120 minutes from the resources in question are displayed in the bottom left of each frame. Coverage maps were calculated and visualized using Redivis (Redivis Inc., Mountain View, CA, USA). Original images have been formatted for stylistic purposes, though scale and calculations have been preserved.

While others have investigated the availability of diagnostics for specific diseases like HIV and sickle cell disease,[31],[32] we examined the availability of basic chemistry and full blood count analyses, which are standard laboratory tests with broad clinical applications. We found that while equipment and staff for laboratory testing were present at most Malawian public hospitals, laboratory testing was often unavailable when needed because of missing reagents or other supplies. This highlights a need for improved supply chain management in Malawi. Moyo et al.[33] surveyed 2 Malawian hospitals and similarly found that laboratory services were often unavailable and that providers doubted laboratory testing accuracy. Our findings reinforce the recommendations outlined by Moyo et al. to strengthen the supply chain and improve laboratory infrastructure.

Thermometers, adult blood pressure cuffs, and pulse oximeters were widely present in Malawi and available at most hospitals. We did not assess the availability of paediatric blood pressure cuffs. Hospitals reporting unavailability of vital signs monitoring often reported that these tools were in use elsewhere or broken and awaiting repairs. The skills or funds to fix broken instruments may be limited in rural Malawi, making it preferable to replace these items, which are generally inexpensive and safely reusable. This could make vital signs monitoring tools a target amenable to donations from the foreign aid community.

Only 49% of Malawians were found to have 1-hour access to electrocardiography. Electrocardiography is essential for managing cardiovascular disease, which is increasingly common, with a prevalence of 8.9%, causing 12% of deaths.[12],[13],[34] Even in the absence of advanced therapeutic modalities, such as percutaneous coronary intervention, diagnosing myocardial infarction via electrocardiography can guide clinicians regarding when to start medical treatments that can significantly reduce the risks of death and reinfarction in the short and long term.[35],[36] Managing heart disease notwithstanding, electrocardiography is also useful for evaluating patients before noncardiac surgery.[37],[38] Purchasing new machines; refurbishing or repairing broken devices; improving supplies of leads, electrodes, and paper; and training local staff in electrocardiography are necessary to improve access. Prioritizing these activities in the 2 central hospitals and 6 district hospitals identified above could expand 1-hour access to 4.7 million more Malawians and 2-hour access to 1.4 million more Malawians.

Only 39% of Malawians had 1-hour access to diagnostic x-ray. All 4 central hospitals and 17 of 25 district hospitals reported unavailability of x-ray in the week before the capacity assessment. X-ray machines were often reported as broken or producing images of inadequate quality to accurately diagnose patients. Acquiring new x-ray machines, repairing broken machines, and distributing machines and consumable supplies are all needed to address the critical shortage in Malawi. Out-of-service medical equipment is

a common problem in low-income countries.[39] Equipment may be left idle when staff lack expertise to operate it, lack resources for repair, or have nowhere to dispose of it when it becomes irreparable.[40] Often with good intentions, well-resourced countries and organizations frequently donate medical equipment to low-income countries, and when such donations proceed without proper coordination, donated equipment can become a liability.[41] Coordination between donors and recipients is critical for minimizing the rate of inappropriate donations.[42] Furthermore, national infrastructure plays a critical role in healthcare provision. Four district hospitals reported x-ray unavailability because of electricity blackouts or surges. Between November 2012 and January 2013, all Malawian district and central hospitals reported periods without electricity or running water, and few facilities had functioning generators.[43] Novel approaches to bringing sustainable, renewable power to rural areas of Malawi merit exploration to boost health sector performance.[44]

This study had several limitations. First, survey data were collected during a single 3-week period in 2018, so the presence and availability of resources could have changed since then. However, without implementation of a nationwide initiative to address capacity, general trends of limited availability are unlikely to have changed significantly. Second, item availability for entire hospitals was reported by a single staff member at each facility and, therefore, may not reflect item availability in all departments. However, we determined high interrater reliability between staff who completed the survey and study investigators who performed independent on-site assessments that involved speaking to multiple staff members and visiting all relevant facilities in 25% of hospitals. Moreover, reported item availability may not reflect appropriate utilization. For example, blood pressure cuffs may be available but unused by nurses working in busy departments or untrained in vital signs monitoring. Even if the machinery and supplies are present to perform x-rays and electrocardiograms, these tools are only helpful if staff are trained to accurately interpret the results. Given the factors that hinder utilization, diagnostics may be inaccessible to more Malawians than we have reported.

Third, as a secondary analysis, this study was limited by the data collected during the original nationwide assessment of musculoskeletal trauma care capacity. For example, when estimating nationwide capacity, we excluded nongovernmental hospitals. Private and mission hospitals care for a significant proportion of the Malawian population, especially in rural areas.[9] Inclusion of these facilities may demonstrate that more Malawians have access to essential diagnostics. Further assessment of nongovernmental facilities, and integration with the public sector, is warranted to improve national healthcare capacity. Ultrasonography capacity was also excluded from this secondary analysis due to limitations in data collected during the capacity assessment. We previously found that ultrasonography capacity was present at every district and central hospital in Malawi and that it was available for diagnosing deep vein thrombosis at all but 6 district hospitals.[8] Our survey focused on the management of patients with femoral shaft fractures and, thus, did not assess the general availability of ultrasonography for obstetric, medical, and surgical diagnoses. This should certainly be examined in future assessments. Moreover, diagnostic capacity is crucial in the management of epidemics, and many of the diagnostics we examined in this study, especially x-ray, are relevant to the management COVID-19.[45] While availability of COVID-19 antigen and antibody tests, personal protective equipment, ventilators, and critical care units was beyond the scope of this study, these should be similarly assessed and prioritized for capacity improvements at governmental and nongovernmental facilities.

Fourth, in our hypothetical intervention, we focused primarily on improving 1-hour access (ETT <60 minutes), rather than 2-hour access, to each diagnostic capability. ETT most accurately estimates travel by private vehicle, which is atypical for many patients.[18],[46] However, we found ETT to be a useful, standardized measure of effective distance to the hospital—albeit in units of time rather than distance—that incorporates road locations, types, and mean speed of travel. Access to a hospital also depends on many factors other than ETT.[26] Transportation infrastructure remains a major barrier to hospital access for many Malawians.[25] True coverage may in fact be lower than estimated even with a more conservative ETT threshold of 60 minutes. While the ETT threshold could be set differently and result in different coverage estimates, the models we developed were helpful for examining geospatial access to essential diagnostics and setting priorities for health system expansion. The *Lancet* Commission on Global Surgery defines "access to timely essential surgery" as the proportion of the population living within an ETT of 120 minutes of a hospital able to perform the bellwether procedures—caesarean delivery, laparotomy, and open fracture treatment.[47] This higher ETT threshold assumes a wider catchment area for hospitals than we used in this study and is appropriate when modelling access to essential surgical services, such as open fracture care, for which patients may need to be transported from rural hospitals to specialized centres that provide such services. However, when estimating access to basic diagnostic resources—resources for which most patients will walk or take public transportation to get to the hospital—we believe that the catchment area for hospitals must be narrowed accordingly when examining geospatial access. A retrospective study used Redivis to show that, between September 2016 and May 2017, most patients visiting the orthopaedic outpatient departments of 4 public hospitals in Malawi were from hometowns with ETTs <60 minutes.[26] We, therefore, believe that an ETT threshold of 60 minutes more appropriately models access to local public hospitals where patients seek basic, essential diagnostics.

Lastly, we chose to limit our recommendations to central hospitals and a selected number of district hospitals to improve the feasibility and reduce the costs of implementing these improvements. However, our recommendations do not incorporate cost estimates, which should be investigated. Costs of resource procurement, distribution, and maintenance should be considered, even when accepting equip-

ment donations.[41] In Malawi, where health expenditure per capita in 2017 was US$32,[10] costs of laboratory reagents, electrocardiographs, and x-ray machines may remain prohibitive of large-scale capacity expansion efforts. Support from international donors and nongovernmental organizations will undoubtedly continue to play an important role in building health system capacity in Malawi.[48]

Conclusions

Diagnostics are foundational to any effective health system. Laboratory testing, electrocardiography, and diagnostic x-ray are essential for diagnosing and monitoring patients with a wide variety of medical and surgical conditions. Unfortunately, these diagnostic capabilities are unavailable in many hospitals throughout Malawi, with less than 60% of the Malawian population having 1-hour access. We recommend prioritizing capacity improvements at all 4 central hospitals and 11 district hospitals, which would expand 1-hour access to these essential diagnostics to 75% of Malawians and 2-hour access to 98% of Malawians nationwide.

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References

1. World Health Organization. *Second WHO Model List of Essential In Vitro Diagnostics*. World Health Organization; 2019. Accessed 3 December 2021. https://www.who.int/medical_devices/publications/Standalone_document_v8.pdf
2. Goossens H, Ferech M, Vander Stichele R, Elseviers M; ESAC Project Group. Outpatient antibiotic use in Europe and association with resistance: a cross-national database study. *Lancet*. 2005;365(9459):579-587. doi:10.1016/S0140-6736(05)17907-0 [View Article] [PubMed]
3. Kralievits KE, Raykar NP, Greenberg SL, Meara JG. The global blood supply: a literature review. *Lancet*. 2015;385 Suppl 2:S28. doi:10.1016/S0140-6736(15)60823-6 [View Article] [PubMed]
4. Wilson ML, Atun R, DeStigter K, et al. The *Lancet* Commission on diagnostics: advancing equitable access to diagnostics. *Lancet*. 2019;393(10185):2018-2020. doi:10.1016/S0140-6736(19)31052-9 [View Article] [PubMed]
5. Manguin S, Foumane V, Besnard P, Fortes F, Carnevale P. Malaria overdiagnosis and subsequent overconsumption of antimalarial drugs in Angola: consequences and effects on human health. *Acta Trop*. 2017;171:58-63. doi:10.1016/j.actatropica.2017.03.022 [View Article] [PubMed]
6. Pramono LA, Setiati S, Soewondo P, et al. Prevalence and predictors of undiagnosed diabetes mellitus in Indonesia. *Acta Med Indones*. 2010;42(4):216-223. [PubMed]
7. Malawi National Statistical Office. *2018 Malawi Population & Housing Census Preliminary Report*. Malawi National Statistical Office; 2018. Accessed 3 December 2021. https://malawi.unfpa.org/sites/default/files/resource-pdf/2018%20Census%20Preliminary%20Report.pdf
8. Agarwal-Harding KJ, Chokotho L, Young S, et al. Assessing the capacity of Malawi's district and central hospitals to manage traumatic diaphyseal femoral fractures in adults. *PLoS One*. 2019;14(11):e0225254. doi:10.1371/journal.pone.0225254 [View Article] [PubMed]
9. Malawi's health and educational systems. Seed Global Health. 29 January 2019. https://seedglobalhealth.org/wp-content/uploads/2015/01/Malawis-Health-and-Educational-Systems.pdf
10. Global health expenditure database. World Health Organization. 2014. Accessed 3 December 2021. https://apps.who.int/nha/database/DocumentationCentre/Index/en
11. GBD Compare. Institute for Health Metrics and Evaluation, University of Washington. 15 October 2020. Updated 21 April 2021. Accessed 3 December 2021. http://www.healthdata.org/data-visualization/gbd-compare
12. Allain TJ, Kinley L, Tsidya B, et al. The spectrum of heart disease in adults in Malawi: a review of the literature with reference to the importance of echocardiography as a diagnostic modality. *Malawi Med J*. 2016;28(2):61-65. doi:10.4314/mmj.v28i2.7 [View Article] [PubMed]
13. Bowie C. The burden of disease in Malawi. *Malawi Med J*. 2006;18(3):103-110. [View Article] [PubMed]
14. Health nutrition and population statistics. The World Bank. Updated 29 October 2021. Accessed 3 December 2021. https://datacatalog.worldbank.org/dataset/health-nutrition-and-population-statistics
15. Varela C, Young S, Groen R, Banza L, Mkandawire NC, Viste A. Untreated surgical conditions in Malawi: a randomised cross-sectional nationwide household survey. *Malawi Med J*. 2017;29(3):231-236. doi:10.4314/mmj.v29i3.1 [View Article] [PubMed]
16. Young S, Banza L, Munthali BS, Manda KG, Gallaher J, Charles A. The impact of the increasing burden of trauma in Malawi on orthopedic trauma service priorities at Kamuzu Central Hospital. *Acta Orthop*. 2016;87(6):632-636. doi:10.1080/17453674.2016.1228413 [View Article] [PubMed]
17. Chokotho L, Mulwafu W, Jacobsen KH, Pandit H, Lavy C. The burden of trauma in four rural district hospitals in Malawi: a retrospective review of medical records. *Injury*. 2014;45(12):2065-2070. doi:10.1016/j.injury.2014.10.001 [View Article] [PubMed]
18. Jaffry Z, Chokotho LC, Harrison WJ, Mkandawire NC. The burden of trauma at a district hospital in Malawi. *Trop Doct*. 2017;47(4):286-291. doi:10.1177/0049475517690333 [View Article] [PubMed]
19. Chokotho L, Jacobsen KH, Burgess D, et al. Trauma and orthopaedic capacity of 267 hospitals in east central and southern Africa. *Lancet*. 2015;385 Suppl 2:S17. doi:10.1016/S0140-6736(15)60812-1 [View Article] [PubMed]
20. Nkengasong JN, Mankoula W. Looming threat of COVID-19 infection in Africa: act collectively, and fast. *Lancet*. 2020;395(10227):841-842. doi:10.1016/S0140-6736(20)30464-5 [View Article] [PubMed]
21. Hopman J, Allegranzi B, Mehtar S. Managing COVID-19 in low- and middle-income countries. *JAMA*. 2020;323(16):1549-1550. doi:10.1001/jama.2020.4169 [View Article] [PubMed]
22. Punchak M, Mukhopadhyay S, Sachdev S, et al. Neurosurgical care: availability and access in low-income and middle-income countries. *World Neurosurg*. 2018;112:e240-e254. doi:10.1016/j.wneu.2018.01.029 [View Article] [PubMed]
23. Chu KM, Dell AJ, Moultrie H, et al. A geospatial analysis of two-hour surgical access to district hospitals in South Africa. *BMC Health Serv Res*. 2020;20(1):744. doi:10.1186/s12913-020-05637-0 [View Article] [PubMed]

24. Juran S, Broer PN, Klug SJ, et al. Geospatial mapping of access to timely essential surgery in sub-Saharan Africa. *BMJ Glob Health*. 2018;3(4):e000875. doi:10.1136/bmjgh-2018-000875 [View Article] [PubMed]

25. Varela C, Young S, Mkandawire N, Groen RS, Banza L, Viste A. Transportation barriers to access health care for surgical conditions in Malawi a cross sectional nationwide household survey. *BMC Public Health*. 2019;19(1):264. doi:10.1186/s12889-019-6577-8 [View Article] [PubMed]

26. Agarwal-Harding KJ, Chokotho LC, Mkandawire NC, Martin C Jr, Losina E, Katz JN. Risk factors for delayed presentation among patients with musculoskeletal injuries in Malawi. *J Bone Joint Surg Am*. 2019;101(10):920-931. doi:10.2106/JBJS.18.00516 [View Article] [PubMed]

27. Olsen JA. Theories of justice and their implications for priority setting in health care. *J Health Econ*. 1997;16(6):625-639. doi:10.1016/s0167-6296(97)00010-6 [View Article] [PubMed]

28. Hudson KB, Sinert R. Renal failure: emergency evaluation and management. *Emerg Med Clin North Am*. 2011;29(3):569-585. doi:10.1016/j.emc.2011.04.005 [View Article] [PubMed]

29. DeFilippis AP, Chapman AR, Mills NL, et al. Assessment and Treatment of Patients With Type 2 Myocardial infarction and acute nonischemic myocardial injury. *Circulation*. 2019;140(20):1661-1678. doi:10.1161/CIRCULATIONAHA.119.040631 [View Article] [PubMed]

30. Rami Reddy SR, Cappell MS. A systematic review of the clinical presentation, diagnosis, and treatment of small bowel obstruction. *Curr Gastroenterol Rep*. 2017;19(6):28. doi:10.1007/s11894-017-0566-9 [View Article] [PubMed]

31. Zungu LI, Magombo T, Chikaonda T, et al. A national quality assurance programme for point-of-care testing in Malawi. *Afr J Lab Med*. 2016;5(2):540. doi:10.4102/ajlm.v5i2.540 [View Article] [PubMed]

32. Heimlich JB, Chipoka G, Kamthunzi P, et al. Establishing sickle cell diagnostics and characterizing a paediatric sickle cell disease cohort in Malawi. *Br J Haematol*. 2016;174(2):325-329. doi:10.1111/bjh.13769 [View Article] [PubMed]

33. Moyo K, Porter C, Chilima B, et al. Use of laboratory test results in patient management by clinicians in Malawi. *Afr J Lab Med*. 2015;4(1):277. doi:10.4102/ajlm.v4i1.277 [View Article] [PubMed]

34. Gowshall M, Taylor-Robinson SD. The increasing prevalence of non-communicable diseases in low-middle income countries: the view from Malawi. *Int J Gen Med*. 2018;11:255-264. doi:10.2147/IJGM.S157987 [View Article] [PubMed]

35. Randomised trial of intravenous streptokinase, oral aspirin, both, or neither among 17,187 cases of suspected acute myocardial infarction: ISIS-2. ISIS-2 (Second International Study of Infarct Survival) Collaborative Group. *Lancet*. 1988;2(8607):349-360. doi:10.1016/S0140-6736(88)92833-4 [View Article] [PubMed]

36. Yusuf S, Lessem J, Jha P, Lonn E. Primary and secondary prevention of myocardial infarction and strokes: an update of randomly allocated, controlled trials. *J Hypertens Suppl*. 1993;11(4):S61-S73. [PubMed]

37. Correll DJ, Hepner DL, Chang C, Tsen L, Hevelone ND, Bader AM. Preoperative electrocardiograms: patient factors predictive of abnormalities. *Anesthesiology*. 2009;110(6):1217-1222. doi:10.1097/ALN.0b013e31819fb139 [View Article] [PubMed]

38. Williams FM, Bergin JD. Cardiac screening before noncardiac surgery. *Surg Clin North Am*. 2009;89(4):747-vii. doi:10.1016/j.suc.2009.05.001 [View Article] [PubMed]

39. Perry L, Malkin R. Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world? *Med Biol Eng Comput*. 2011;49(7):719-722. doi:10.1007/s11517-011-0786-3 [View Article] [PubMed]

40. Dzwonczyk R, Riha C. Medical equipment donations in Haiti: flaws in the donation process. *Rev Panam Salud Publica*. 2012;31(4):345-348. doi:10.1590/s1020-49892012000400012 [View Article] [PubMed]

41. World Health Organization. *Medical Device Donations: Considerations for Solicitation and Provision. WHO Medical Device Technical Series*. World Health Organization; 2011. Accessed 18 December 2021. https://apps.who.int/iris/handle/10665/44568

42. Marks IH, Thomas H, Bakhet M, Fitzgerald E. Medical equipment donation in low-resource settings: a review of the literature and guidelines for surgery and anaesthesia in low-income and middle-income countries. *BMJ Glob Health*. 2019;4(5):e001785. doi:10.1136/bmjgh-2019-001785 [View Article] [PubMed]

43. Henry JA, Frenkel E, Borgstein E, Mkandawire N, Goddia C. Surgical and anaesthetic capacity of hospitals in Malawi: key insights. *Health Policy Plan*. 2015;30(8):985-994. doi:10.1093/heapol/czu102 [View Article] [PubMed]

44. Eales A, Alsop A, Frame D, Strachan S, Galloway S. Assessing the market for solar photovoltaic (PV) microgrids in Malawi. *J Sustain Res*. 2020;2(1):e200008. doi:10.20900/jsr20200008 [View Article]

45. Wong HYF, Lam HYS, Fong AH, et al. Frequency and distribution of chest radiographic findings in patients positive for COVID-19. *Radiology*. 2020;296(2):E72-E78. doi:10.1148/radiol.2020201160 [View Article] [PubMed]

46. Samuel JC, Akinkuotu A, Villaveces A, et al. Epidemiology of injuries at a tertiary care center in Malawi. *World J Surg*. 2009;33(9):1836-1841. doi:10.1007/s00268-009-0113-4 [View Article] [PubMed]

47. Meara JG, Leather AJ, Hagander L, et al. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet*. 2015;386(9993):569-624. doi:10.1016/S0140-6736(15)60160-X [View Article] [PubMed]

48. Malawi health system strengthening fact sheet. USAID. Updated 15 September 2016. Accessed 18 December 2021. https://www.usaid.gov/malawi/fact-sheets/malawi-health-systems-strengthening-fact-sheet

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