

The Power of Mobile Health: The Girl With the Gadgets in Uganda*

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Abstract

Medical-grade ultrasound devices are now pocket sized and can be easily transported to underserved parts of the world, allowing health care providers to have the tools to optimize diagnoses, inform management plans, and improve patient outcomes in remote locations. Other great advances in technology have recently occurred, such as artificial intelligence applied to mobile health devices and cloud computing, as augmented reality instructions make these devices more user friendly and readily applicable across health care encounters. However, broader awareness of the impact of these mobile health technologies is needed among health care providers, along with training on how to use them in valid and reproducible environments, for accurate diagnosis and treatment. This article provides a summary of a Mayo International Health Program journey to Bwindi, Uganda, with a portable mobile health unit. This article shows how point-of-care ultrasonography and other technologies can benefit remote clinical diagnosis and management in underserved areas around the world.

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How can health care be improved on a global scale in terms of its value to patients, regardless of their health economic status, presence or absence of health insurance, and first-world or third-world—country status? Health care economists propose seeing health care delivery through the lens of the value equation, $V = Q/C$, in which V is value, Q is quality or outcomes, and C is costs.¹ In the United States, the Organization for Economic Cooperation and Development focuses on advancing public health, which is similar to the mission of the National Institutes of Health. In 1948, the World Health Organization defined health as a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity.² In 1986, the World Health Organization clarified the definition of health as being a resource for everyday life, not only the objective of living but rather a positive concept, emphasizing social and personal resources as well as physical capacities.²⁻⁴ The word “resource” appears frequently in the definition of health, which implies that health is composed of resources to deal with physical, mental, and social issues.

We sought to use the resources of the Mayo International Health Program (MIHP) to observe and learn about health in underserved parts of the world and witness firsthand the difference in availability of resources in other countries. For this MIHP mission, we were given the opportunity to travel to Bwindi, Uganda, in November 2019. This article focuses on the use of a portable mobile health unit (MHU) with portable ultrasounds^{5,6} as an added relatively low-cost resource for the Bwindi Community Hospital and its potential impact on the global health value equation in terms of diagnostic and management decision making.

METHODS

We report a largely descriptive and retrospective narrative review of a small anonymous case series from an MIHP rotation. The MIHP was started in 2001, by Mayo Clinic, to help broaden experience to underserved areas all over the world.^{7,8} The lead author (C.L.O.) applied to the MHIP program in 2019 and was selected for a mission in November 2019, in Uganda, Africa.



MIHP Events

The MIHP assigned a 4-week rotation at the Bwindi Community Hospital in November 2019. In keeping with the definition of health as a resource, we brought an MHU to enhance local diagnostic and health care value decision making. The rationale was that this clinic essentially had no advanced technology to help triage patients beyond the physical examination to support decision making regarding selection of patients for referral to higher-level hospitals in the country.

Resources. The MHU comprised 2 portable ultrasound units, donated in-kind by FUJIFILM Sonosite, Inc (Bothwell, Washington), a digital stethoscope with 1 lead electrocardiogram donated in-kind by Eko Devices Inc. (Oakland, California), compatible with iPhone (Apple Inc., Cupertino, California), and an otoscope with video (Figure 1).

RESULTS

After the 4-week rotation, a total of 391 patients had been seen: an average of 17 patients per day. This is a modest number, as the true number of patients seen is higher than 391 when private wards and pediatric patients are included. The Eko Device was used in all patient encounters. Among the patients seen in Bwindi, we performed approximately 46 point-of-care ultrasound (POCUS) examinations in 33 patients during a period of 23

days (approximately 2 examinations per day). Lung, cardiac, optic nerve, vascular, and abdominal ultrasounds were performed according to clinical relevance (Supplemental Figures 1-4, available online at <http://mcpiqjournal.org>). The POCUS examinations took, on average, 10 to 20 minutes, depending on amount of ultrasound clarity and anatomic difficulties. In 15 of the 18 (83.3%) documented cases, use of these bedside diagnostic tools enhanced the formation of diagnoses and thereby positively



FIGURE 2. Active clot in the femoral vein and noncompressible femoral vein.

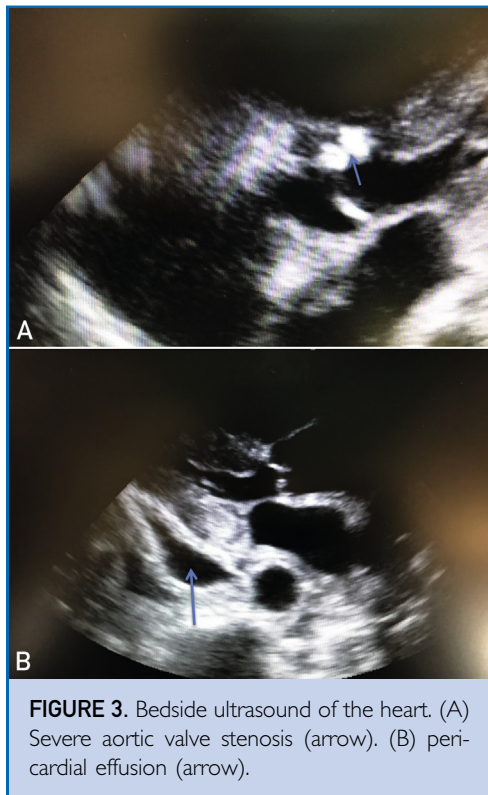


FIGURE 3. Bedside ultrasound of the heart. (A) Severe aortic valve stenosis (arrow). (B) pericardial effusion (arrow).

affected the management and outcomes of these patients. In 4 of the 18 (22.2%), the initial diagnosis was confirmed, and management approach remained unchanged (Table).

Illustrative Cases and Examples of MHU-Enhanced Decision Making and Procedures

To illustrate the clinical decision-making utility of the MHU in Uganda, we are highlighting some specific uses of ultrasound during the rotation. The cases that follow were selected because of their impact on patients, their families, and the team.

Case 1: Decompensated Heart Failure With Preserved Ejection Fraction in a Pediatric Patient With Anemia.

We performed a cardiac ultrasound examination on a 15-year-old girl with chronic anemia who required multiple blood transfusions. She had a history of chronic kidney disease and probable heart failure. The POCUS examination showed small-to-moderate pericardial effusion, hyperdynamic heart, and suspicion for a thrombus or calcification within the left ventricle. We

sent the ultrasound video (without patient identifiers) to a consultant (C.V.B.) in the United States. The initial suspicion was that the finding was an artifact; however, on further review, the determination was made that there was a calcification in the left ventricle attached to the inferoposterior wall (Supplemental Figure 2, available online at <http://mcpiqjournal.org>). The patient's abdominal ultrasound showed a cystic mass in the left kidney and right renal agenesis. This developmental malformation caused poor erythropoietin production and likely contributed to her severe anemia and heart failure with preserved ejection fraction (HFpEF). There is no doubt that other contributors, such as malnutrition and possible other genetic malformations, played an important role, as our 15-year-old patient appeared to be only 8 years old. Even though there was no edema on physical examination, she was initiated on furosemide and digoxin to support the need for further blood transfusions. In a 24-hour follow-up POCUS examination, the patient's heart appeared less hyperdynamic, and the ejection fraction was normal (above 50% by Simpson biplane method). Therefore, digoxin was stopped, and later furosemide was also discontinued. Although we were able to obtain a better apical chamber view, it was still challenging to determine whether there was a small thrombus in the left ventricle.

Case 2: A Hypertensive Emergency in a Pediatric Patient.

A 13-year-old boy presented with systolic blood pressure in the 160s and headache. Review of systems also revealed vomiting and loose stools. The patient was started on captopril and furosemide. With limited resources, a battery of diagnostic tools was ordered. Urinalysis showed 1 red cell cast, red cell smudge, and positive protein. A renal profile was collected. A formal abdominal ultrasound showed mild hydronephrosis, mild portal hypertension, and mild ascites. Because of worsening hypertension (blood pressure, 200s/130s), nifedipine was added to his therapy. The POCUS examination showed ejection fraction 77%, hypertrophic left ventricle, dilated left atrium suggesting diastolic dysfunction, and no pericardial effusion (Supplemental Figure 3, available online at <http://mcpiqjournal.org>). At the time, the

TABLE. How Mobile Health Technology Factored Into Clinical Decision Making

Case	Patient	Initial diagnosis	Presentation of ultrasound findings	Final diagnosis	Change in diagnosis/treatment
1	23-year-old woman with abdominal pain	Pelvic inflammatory disease	Heart: Systolic dysfunction with regional motion abnormalities Lung: Pleural effusion. Abdomen: Hepatic congestion with no ascites (Video 1, available online at http://mcpiqjournal.org)	Possible infection with cardiomyopathy vs congenital cardiomyopathy	Yes. Furosemide was added to the treatment plan. In the following days, repeat ultrasound showed mitral valve E-point septal separation of 14.5 mm (improved), and patient appeared to have clinically improved
2	Elderly woman with high systolic BP (235/65), low heart rate (34 bpm), and poor ECG quality	Hypertensive emergency and heart block	Heart: Left-ventricular global hypokinesis, worse in the septal and apical wall, with EF 30% Lung: B lines	Heart failure with reduced EF, second-degree heart block with concern for progression to third-degree heart block	Yes. Optimized diuretic and BP medication management and prompted referral for pacemaker
3	Young man, unresponsive for 2 weeks	Coma	Optic nerve sheath ultrasound in comatose patient. Less than 5 mm intracranial pressure less likely than 20 mm (Supplemental Figure 1, available online at http://mcpiqjournal.org)	Low optic nerve diameter, inferred that intracranial pressure was not elevated. Unresponsiveness, possibly secondary to seizures	No. Antiepileptic medication trial initiated
4	Elderly man with bilateral lower extremity edema, history of HTN, medication unknown	Bilateral lower extremity edema	Heart: EF 50% or more via visual estimate, thicken wall of LV, no pericardial effusion	Uncontrolled HTN leading to valve incompetence	Yes. Recommended HTN medications, renal panel, and liver panel testing owing to the area tested for filariasis
5	Middle-aged man with HIV and bilateral pitting edema	Cellulitis	Vascular: Lower-extremity bilateral ultrasound showed a long right femoral vein thrombosis (Figure 2)	Deep vein thrombosis	Yes. Full dose anticoagulation started
6	50-year-old woman with more than 2 years of substantial weight loss	Failure to thrive	Heart: Hyperdynamic heart	TB test positive. Chest radiography showed left upper lung lesion, likely TB focus	No
7	100-year-old uncooperative woman	Anasarca, cause unknown	Heart: Extensively calcified/stenotic aortic valve and thickening of LV with very	Acute decompensated heart failure from severe aortic stenosis	Yes. Increased dose and frequency of furosemide; unfortunately, the patient died

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TABLE. Continued

Case	Patient	Initial diagnosis	Presentation of ultrasound findings	Final diagnosis	Change in diagnosis/treatment
			small chamber diameter remaining, large pericardial effusion. Abdomen: very large ascites (Video 2 , Figure 3)		
8	Outpatient elderly man with HIV with left unilateral arm and leg edema (hemibody) and engorged hemibody veins	None	Vascular: Left femoral vein noncompressible with bright clot. Left upper extremity veins noncompressible, no bright clot, hypodense material seen	Working differential diagnosis: Medication induced vs elephantiasis vs HIV lymphoma vs HIV neuritis vs parasite infection	Yes. Borden differential and focused testing
9	Outpatient 52-year-old man with leg edema for 20 years	None	Heart: EF within normal limit, no severe abnormalities seen	Heart failure was ruled out	No: Heart failure was ruled out, but other differentials were filariasis, venous insufficiency from incompetence valves; patient was encouraged to get renal and liver profile, to test for filariasis, and to wear compression stockings. The results were shared with the patient and his brother with strong disclaimer: "This is not a formal ECHO, formal ECHO is required;" they verbalized understanding
10	Young adult man presented with tingling, parenthesis, numbness, weakness, and abdominal pain, ongoing for a year	None. Physical examination: Hyperreflexia, strength 4/5 diffusely; otherwise, all within normal limits	Heart: No abnormalities seen	None	No. Differential diagnosis: Radiculopathy vs inflammatory peripheral disease. List of suggested labs and imaging given to the patient; recommended multivitamin, magnesium, and anti-inflammatory diet

bpm, beats per minute; BP, blood pressure; ECG, electrocardiogram; ECHO, echocardiogram; EF, ejection fraction; HTN, hypertension; LV, left ventricle; TB, tuberculosis.

differential diagnosis was broad and included glomerulonephritis from streptococcus or hepatitis A, focal segmental glomerulosclerosis, minimal change disease, HIV, tuberculosis, lupus erythematosus, aortic dissection, or coarctation of the aorta. Chest radiography was reviewed with a consultant (C.R.) in the United States, who responded as follows: "I don't see a size change in aortic caliber, though it is only anterior-posterior view. There are no additional signs of rib notching or collateralization." On a follow-up POCUS examination, there appeared to be a small pericardial effusion in the subcoastal view, and lung examination revealed B lines, suggesting interstitial fluid in the lung, supporting continuation with current therapy. The local hospital laboratory was unable to perform antistreptolysin O titer or hepatitis A screening because of lack of resources. Over time, his blood pressure improved, but the patient was still complaining of headache and discomfort. Referral to a higher-level facility where further testing was available was discussed with the family; however, they could not afford more testing, and the family took the patient home against medical advice.

Case 3: Headache, Weakness, and Hyponatremia. An 80-year-old woman with acute onset of headache and weakness without fever that started 4 days before presentation was brought to the hospital in a wheelchair by her family. She was found to have a sodium level of 122 mEq/L and potassium level of 2 mEq/L. Intravenous fluid with normal saline (0.9%), potassium replacement, and empiric ceftriaxone were started. During our evaluation, she was febrile and hypoxic (oxygen saturation in the 80s) and had accumulation of oral secretion in her mouth. Her neurologic physical examination was as follows: not following commands; Glasgow Coma Scale score of 11 (eyes, 3; verbal, 3; motor, 5); moving all extremities spontaneously but not to commands; upper extremity holding up against gravity but not the lower extremity; normal muscle tone; and sensation intact. Because of her initial presentation of headache, altered mental status, and the new finding of extremity weakness, there was concern of a possible intracranial hemorrhage, which is known to cause hyponatremia. Other differential

diagnoses included sepsis and primary hyponatremia from poor diet or recent illness. Following examination, she was initiated on broad-spectrum antibiotics and supplemental oxygen with cardiac monitoring. Transfer to a facility with a critical care unit and computed tomography capabilities were considered, but the transfer never occurred. At bedside, during our POCUS examination, we attempted transcranial Doppler with phased array probe, but the patient had poor skull sonographic windows. The optic nerve sheath measurement demonstrated a left 4.8 mm and right 4.2 mm in diameter, suggesting no increased intracranial pressure. Over the next 2 days, her Glasgow Coma Scale score improved with no focal deficit, and 2 days later she returned to her baseline level and was able to stand with assistance and walk with her cane. Her rapid improvement without specific intervention makes intracranial hemorrhage less likely or, if present, a possible small and stable bleed.

Case 4: Unfortunate Case of Respiratory Distress. A pediatric patient was brought to the hospital with symptoms of unresponsiveness and respiratory distress for 3 days. His physical examination revealed Glasgow Coma Scale score of 7 (eyes, 1; verbal, 1; motor, 5), considerable lung crackles, congested breath sounds, poor air entry, and tachypnea. He was given oxygen at 3 L/min via nasal cannula, a blood transfusion, and furosemide (given the previous day). The POCUS revealed a dilated right atrium, likely caused by high chamber pressure, multiple B lines, and a right consolidated lung, but there was no pericardial effusion or pleural effusion. We provided the following recommendations: Optimize supplemental oxygen, administer emergent furosemide and nebulized albuterol, stop intravenous fluids, broaden antibiotics, and perform pulmonary hygiene. The patient had thick airway secretion and was biting the suctioning tube. He did not respond to therapy, and after remaining in the same state for 2 days, with no possibility of transfer to a higher-level facility, he died.

Use of Ultrasound for Procedure: Ultrasound-Guided Paracentesis

Initially, the providers at Bwindi Community Hospital were performing paracentesis

without ultrasound; however, they were interested in learning how to perform abdominal ultrasound for paracentesis and were quick to learn (Supplemental Figure 4, available online at <http://mcpiqjournal.org>).

Enabling Providers to Work Independently: New Skills in Cardiac, Optic Nerve, and Doppler Ultrasonography

By 3 weeks into the rotation, 2 consultants were performing cardiac and optic nerve sheath ultrasound independently. A nurse watched us perform a Doppler ultrasound and was able to perform 1 on his own and acquired the following results in a patient with left-foot gangrene: no artery Doppler signals on the left extremity of the femoral vessels compared with the right, which had good Doppler signals (Video 3, available online at <http://mcpiqjournal.org>). These findings were confirmed by a trained sonographer and interpreter, who performed the formal ultrasound. Use of this diagnostic tool informed the need for surgical intervention, and the patient ultimately had an above-the-knee amputation rather than medical therapy alone.

DISCUSSION

The MIHP allowed for an incredible experience to enrich medical and procedural knowledge in an underserved region of the world. Bwindi, Uganda was an eye-opening

experience, where we noted the luxuries available to us at Mayo Clinic and within US health care: access to a wide range of specialists and subspecialists (surgeons and medical) and services. Advanced and expensive technologies—intensive care equipment, ventilators, and advanced diagnostics such as computed tomography and magnetic resonance imaging—were unavailable in Bwindi. Despite this challenge, the MHU concept was deployed successfully, as were aspects of telemedicine from Mayo subspecialists, when available. These findings are critically important and can be reproduced using an interconnected world of health care providers, the internet, and 4G and 5G networks across the globe, especially during the coronavirus disease 2019 (COVID-19) pandemic.

Limitations

Limitations to this report include the retrospective design, limited nature of observations, and selection bias. Yet, we believe that the insights gained from the MIHP experience and the MHU concept can provide tremendous value to rural and other underserved areas worldwide and raise the value of health care using newer, lower-cost technologies such as ultrasound.⁹ Moore's law over the past several decades has made it possible for technology to get smaller, faster, and cheaper than ever before, and mobile (smart) phones now run operating systems and have computing power that exceeds the Apollo NASA missions that sent astronauts to the moon decades ago.

We believe that local diagnoses and treatment plans may be affected by incorporating the information obtained through bedside ultrasonography and similar small devices as an extension of the physical examination.¹⁰ We acknowledge that the physical examination is the cornerstone to accurate diagnosis in medicine, and the clinicians in Bwindi are masterful in their clinical examination techniques. Our limited MHU data suggest that in approximately 80% of our clinical encounters, supplementation of the history and physical examinations with these added health care technologies resulted in substantially improved diagnostics.

Further, there appeared to be educational value in using these technologies in Uganda.¹⁰ Our ability to teach nurses and other

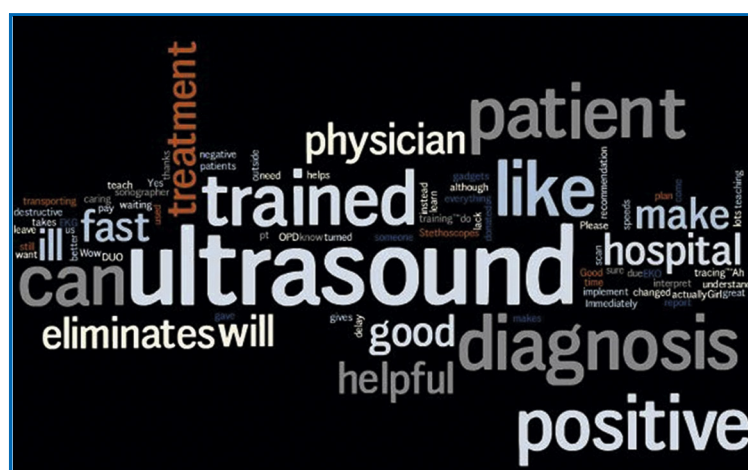


FIGURE 4. Uganda health care providers' feelings about the mobile health unit used during the Mayo International Health Program experience.

physicians how to use these various tools greatly enhanced their standard methods of assessment and diagnostic decision making. Of note, the MHU appeared to be clinically practical for use in remote areas, as it proved to be user friendly and required minimal charging to operate. The Eko DUO digital stethoscope maintains a full battery for weeks; over the 4-week rotation required charging only twice (Supplemental Figure 5, available online at <http://mcpiqjournal.org>). All health care workers in the hospital reported high satisfaction working with the Eko Device compared with their standard stethoscope and later became interested in purchasing it. They particularly liked that selected auscultation and electrocardiogram clips could be shared with others for learning and teaching, especially when compared with ultrasound findings in conjunction with classical physical examination findings. In addition, these findings could be deidentified (for patient confidentiality) and viewed multiple times on a smart phone. Many clinicians also saw the value of ultrasound to augment clinical physical examination findings as described here for diagnostic and potential procedural visualization.

We acknowledge additional limitations inherent to any technology or tool in health care, with cost being a major one even in 2020.⁹ Further, there was concern about the murmur-detection sensitivity of the digital stethoscope, as some users could not hear the murmurs it detected while listening to the patient but were able to hear the murmur during replay or review. Any technology has limits in what it offers the clinician and cannot be the sole factor for all diagnostic and therapeutic decision making. Another limitation and learning experience was that there was often muscle artifact on several electrocardiogram tracings, which may have represented patients' pectoralis muscles in a sitting position vs being recumbent in a supine and relaxed position. This was easy to overcome by adapting the physical examination techniques. We found data filtering for these devices could be improved to limit artifacts.

Another limitation to this experience includes lack of formal education and training for the local clinicians in performing ultrasound and using the electrocardiogram and

digital stethoscope. However, this may be overcome by organizing a formal training session with a curriculum that can be completed in a few days.¹⁰ Another limitation is the logistics of individuals acquiring their own ultrasounds and the inability to save these clips to review later; our team had to return to the United States with the ultrasound machines and erase (and deidentify) the clips that we brought with us. All of these limitations can be overcome, as ultrasounds are becoming less and less expensive. We therefore hope that this report can help inspire creative philanthropic support and donations to help underserved areas of the world to purchase equipment similar to the MHU. We realize that, despite decreasing costs, budgetary constraints may be prohibitive for many clinics and hospitals; perhaps, over time, the costs will fall to a point at which they can be purchased to add value to local care and expand the scope of MHUs to augment physical examination skills. Although each health care community should evaluate the true value of these technologies in their own context, the technologies we describe appear safe and noninvasive. These can be used in conjunction with augmenting physical examination skills, are relatively simple to operate, and are becoming more widely available to used both for diagnosis and therapeutic purposes.^{8,9} A final visual summary is provided by a "word doodle" composed of comments from nurses and physicians in Uganda about the mobile health tools used in the MIHP experience (Figure 4).

CONCLUSION

The value of global health care delivery is changing rapidly and improving over time because of declining costs of MHU technologies. We describe this value through our experience in a community in Uganda. The global COVID-19 pandemic has forced a discussion on how to scale mobile health solutions rapidly at the point of care. Mobile health has emerged as a result of Moore's law, which has allowed smaller, faster, cheaper mobile smart phones, along with emergence of global connectivity via cellular and internet broadband (4G, 5G) communication systems. We changed the initial diagnosis and treatment 80% of the time with our MHU. We were very proud that local

providers were performing ultrasounds by themselves by the end of the rotation and that they were very excited to learn more.

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SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at <http://mcpiqjournal.org>. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: HFpEF = heart failure with preserved ejection fraction; MHU = mobile health unit; MIHP = Mayo International Health Program; POCUS = point-of-care ultrasound

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