Tropical Medicine and International Health doi:10.1111/tmi.12657

VOLUME 21 NO 3 PP 294–311 MARCH 2016

Systematic Review

The use of portable ultrasound devices in low- and middle-income countries: a systematic review of the literature

Dawn M. Becker[1], Chelsea A. Tafoya[2], Sören L. Becker[3,4,5], Grant H. Kruger[6], Matthew J. Tafoya[2] and Torben K. Becker[7]

1 *Department of Internal Medicine, St. Joseph Mercy Hospital Ann Arbor – St. Joseph Mercy Health System, Ann Arbor, MI, USA*
2 *University of Michigan Medical School, Ann Arbor, MI, USA*
3 *Department of Epidemiology and Public Health, Swiss Tropical and Public Health Institute, Basel, Switzerland*
4 *University of Basel, Basel, Switzerland*
5 *Institute of Medical Microbiology and Hygiene, Saarland University Medical Center, Homburg/Saar, Germany*
6 *Department of Mechanical Engineering, College of Engineering, University of Michigan, Ann Arbor, MI, USA*
7 *Department of Critical Care Medicine, University of Pittsburgh Medical Center, Pittsburgh, PA, USA*

Abstract

OBJECTIVES To review the scientific literature pertaining to the use of hand-carried and hand-held ultrasound devices in low- and middle-income countries (LMIC), with a focus on clinical applications, geographical areas of use, the impact on patient management and technical features of the devices used.

METHODS The electronic databases PubMed and Google Scholar were searched. No language or date restrictions were applied. Case reports and original research describing the use of hand-carried ultrasound devices in LMIC were included if agreed upon as relevant by two-reviewer consensus based on our predefined research questions.

RESULTS A total of 644 articles were found and screened, and 36 manuscripts were included for final review. Twenty-seven studies were original research articles, and nine were case reports. Several reports describe the successful diagnosis and management of difficult, often life-threatening conditions, using hand-carried and hand-held ultrasound. These portable ultrasound devices have also been studied for cardiac screening exams, as well as a rapid triage tool in rural areas and after natural disaster. Most applications focus on obstetrical and abdominal complaints. Portable ultrasound may have an impact on clinical management in up to 70% of all cases. However, no randomised controlled trials have evaluated the impact of ultrasound-guided diagnosis and treatment in resource-constrained settings. The exclusion of articles published in journals not listed in the large databases may have biased our results. Our findings are limited by the lack of higher quality evidence (e.g. controlled trials).

CONCLUSIONS Hand-carried and hand-held ultrasound is successfully being used to triage, diagnose and treat patients with a variety of complaints in LMIC. However, the quality of the current evidence is low. There is an urgent need to perform larger clinical trials assessing the impact of hand-carried ultrasound in LMIC.

keywords ultrasound, resource-constrained settings, clinical examination, diagnosis

Introduction

Ultrasound is a widely used clinical imaging modality for rapid diagnosis and treatment at the bedside, does not require any additional personnel and is relatively easy to learn [1]. It does not expose patients or medical personnel to ionising radiation and can be portable and operated with rechargeable batteries. It is for these reasons that there has been significant interest in employing this technology in low- and middle-income countries (LMIC), as it requires less infrastructure and training than other imaging systems such as computed tomography or magnetic resonance imaging. In a 1985 landmark report on the future use of imaging technologies in

developing countries, WHO concluded that there are 'very real advantages to be gained from the use' of ultrasound, and noted its potential for 'improved patient management and care of the individual' [2].

In the 1990s, the first portable ultrasound machine – it could be carried in a backpack – was developed [3]. Since the turn of the millennium, reports on ultrasound use and training in LMIC have increased exponentially. However, widespread adoption is still limited by the cost of most ultrasound machines, limited distribution and support networks, as well as lack of access to replacement parts [4]. Other significant barriers that may further preclude the use in mobile clinics or peripheral healthcare centres are only intermittent power supply to recharge batteries, or unsafe storage. In the last few years, however, a new generation of hand-carried and even hand-held ultrasound devices has emerged. The key difference is that hand-held ultrasound systems can be used while holding the display unit and probe using either one or two hands, while hand-carried systems are typically larger, requiring a surface on which to place the ultrasound unit prior to performing the scan. Both hand-carried and hand-held devices are characterised by low cost, a more rugged mechanical design that withstands rough environments, and use of affordable batteries that can be replaced easily. It follows that these new ultrasound devices can be carried around with ease by a clinician and may be handed over at the end of the work period to the covering colleague, thus obviating the need for safe storage. They can be integrated into the physical examination and initial assessment of a patient, much like a stethoscope, making the bedside application of ultrasound easier than where a patient has to be transported to a stationary machine [5].

Despite the considerable potential of ultrasound-based imaging to improve the diagnosis of many medical conditions and to guide individual patient management, little is known about the current practices in LMIC, such as the extent of use of portable ultrasound devices, major indications for the use of ultrasound techniques and impact on patient outcome. We conducted a systematic review of the literature to elucidate where and how hand-carried and hand-held ultrasound devices are being used in LMIC, asking (i) What are the uses and applications of hand-carried and hand-held ultrasound devices in LMIC? (ii) In which geographic regions are hand-carried and hand-held ultrasound devices being used? (iii) What is the impact of hand-carried and hand-held ultrasound devices on patient management? (iv) What hand-carried and hand-held ultrasound devices are available, and what are their technical specifications?

We critically assess diseases and clinical situations in which the systematic introduction of clinical ultrasound examinations at the bedside might be most beneficial, and also identify drawbacks and research needs.

Methods

We performed a systematic literature review to address the above-mentioned questions. Two authors (CT, MT) searched the electronic database PubMed independently for the search terms shown in Box 1. This was supplemented by a manual Google Scholar search and a manual review of the bibliographies. The manual search was limited to English language articles. LMIC were defined based on the World Bank definition of 'developing countries' (available at http://data.worldbank.org/about/country-and-lending-groups).

For the PubMed search, there were no data range (beyond those intrinsic to the PubMed database) and language restrictions. The search terms and search strategy were chosen in consultation with the global health librarian at the University of Michigan. We excluded opinion articles and commentaries. The last search was completed on 8 July 2015.

Study selection and data abstraction were performed independently by two reviewers with clinical experience pertaining to the use of ultrasound in LMIC (DMB, TKB) according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement [6]. Any discrepancies between the two reviewers were resolved by consensus.

Original research articles and case reports were included if a manuscript was deemed relevant to any of the primary research questions addressed by this review as stated above. Case reports that addressed the primary research questions were included given the novel character of hand-carried (defined as below 4 kg) and hand-held ultrasound devices. Articles describing the use of such devices by military units from high-resource countries within a military hospital in an LMIC but equipped and operated by the high-resource nation were excluded during the screening process.

Raw data were extracted using a standardised template that included the first author, the year of publication, the title, the journal and the article was published in, study design, ultrasound device used, the geographical region where the study was performed, the environment in which ultrasound was used and the article's key findings (number of study subjects, study subject characteristics, details regarding interventions and outcome).

A dedicated technology evaluation was completed by an engineer (GHK), describing the currently available

Box 1 The search string

((((((((ultrasound[Title/Abstract] AND africa[Title/Abstract])))) OR ((resource-limited[Title] AND ultrasound[Title]))) OR ((bedside[Title] AND ultrasound[Title])))) OR (((ultrasound[Title/Abstract] OR ultrasonography[Title/Abstract] OR echocardiography[Title/Abstract])) AND (handheld[Title/Abstract] OR hand-carried[Title/Abstract] OR portable [Title/Abstract] OR pocket[Title/Abstract] OR point-of-care[Title/Abstract]))))) AND (afghanistan OR guatemala OR pakistan OR albania OR guinea OR palau OR algeria OR guinea bissau OR panama OR angola OR guyana OR papua new guinea OR argentina OR haiti OR paraguay OR armenia OR honduras OR peru OR azerbaijan OR india OR philippines OR bangladesh OR indonesia OR romania OR belarus OR iran OR rwanda OR belize OR iraq OR samoa OR benin OR jamaica OR sao tome and principe OR bhutan OR jordan OR senegal OR bolivia OR kazakhstan OR serbia OR bosnia and herzegovina OR kenya OR seychelles OR botswana OR kiribati OR sierra leone OR brazil OR korea OR solomon islands OR bulgaria OR kosovo OR somalia OR burkina faso OR kyrgyz republic OR south africa OR burundi OR lao pdr OR south sudan OR cabo verde OR lebanon OR sri lanka OR cambodia OR lesotho OR st. lucia OR cameroon OR liberia OR st. vincent and the grenadines OR central african republic OR libya OR sudan OR chad OR macedonia OR suriname OR china OR madagascar OR swaziland OR colombia OR malawi OR syria OR comoros OR malaysia OR tajikistan OR congo OR maldives OR tanzania OR congo OR mali OR thailand OR costa rica OR marshall islands OR timor-leste OR côte d'ivoire OR mauritania OR togo OR cuba OR mauritius OR tonga OR djibouti OR mayotte OR tunisia OR dominica OR mexico OR turkey OR dominican republic OR micronesia OR turkmenistan OR ecuador OR moldova OR tuvalu OR egypt OR mongolia OR uganda OR el salvador OR montenegro OR ukraine OR eritrea OR morocco OR uzbekistan OR ethiopia OR mozambique OR vanuatu OR fiji OR myanmar OR vietnam OR gabon OR namibia OR palestine OR gambia OR nepal OR yemen OR georgia OR nicaragua OR zambia OR ghana OR niger OR zimbabwe OR grenada OR nigeria))

hand-carried and hand-held ultrasound devices, based on information from the manufacturer manuals. Data were extracted and abstracted jointly by the above-mentioned authors. The review protocol has not been previously published or registered.

Results

General findings

The initial database search yielded 644 articles. Manual review of bibliographies generated four additional references. All were screened and assessed for eligibility for full-text review. A total of 591 articles were excluded after review of the abstracts as they did not report on the use of hand-carried or hand-held ultrasound as defined for this review, described non-clinical applications or reported on studies performed in a non-LMIC context. The remaining 53 articles were manually reviewed, of which 36 with relevant content were selected for inclusion (Figure 1). Of these, 27 were original research studies and nine were case reports (Table 1). Geographically, most articles were from Africa (13/36), followed by Asia (10/36) and South America (6/36). The remaining seven manuscripts came from Haiti (4/36), Turkey (2/36) and Romania (1/36). Notably, 29/36 articles (80.6%) were published after 2010.

Indications for application of portable ultrasound

There is considerable variety in the disease spectrum for which the use of hand-held and hand-carried ultrasound is reported. However, most indications were in the context of acute medical emergencies and for individual patient management. Several studies assessed the role and impact of ultrasound as a screening tool in cardiology and in natural disasters.

Portable ultrasound for individual patient diagnosis and management

A case from Sierra Leone highlights the use of a hand-carried ultrasound device for the diagnosis of a large empyema, and subsequent management of drains and complications [7]. A case from Haiti demonstrates the use of hand-carried ultrasound in the diagnosis and management of intussusception by a clinician without prior practical experience in invasive treatment of this condition [8]. Intussusception was also successfully diagnosed by a non-physician healthcare worker in Uganda using hand-carried ultrasound [9]. Goksu *et al.* describe the management of a post-traumatic pseudoaneurysm using a hand-carried ultrasound device [10]. Another case report from Haiti illustrates the successful use of a hand-carried device to perform ocular ultrasound to assess a child with

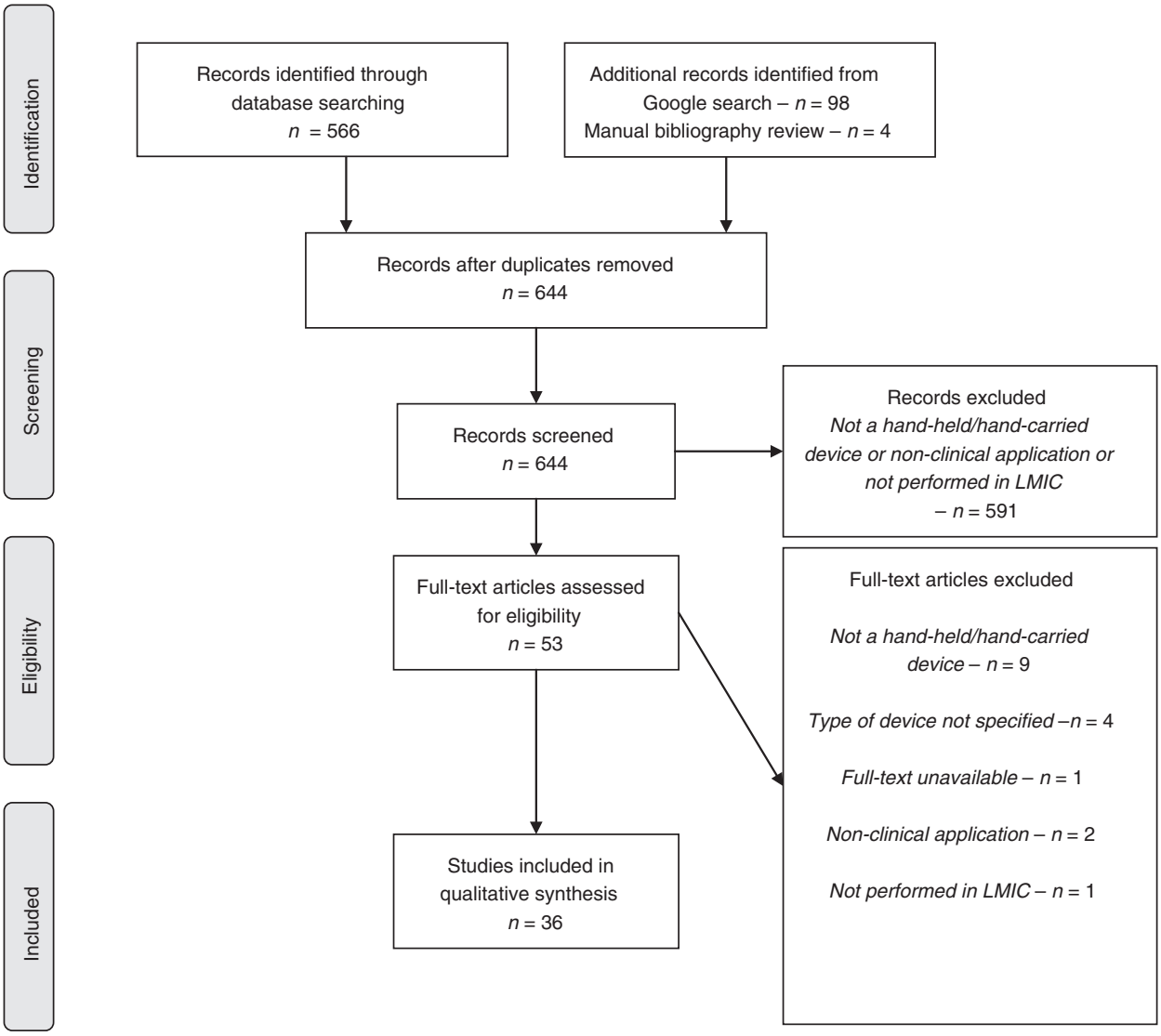

Figure 1 PRISMA flow diagram.

an abnormal eye, ultimately leading to the diagnosis of retinoblastoma [11]. Foreign body localisation and removal, a common bedside ultrasound application, was also successfully performed using hand-carried ultrasound [12]. Samanta *et al.* report how bedside ultrasound using a hand-carried machine was used to guide cardiopulmonary resuscitation of a patient with situs inversus in India [13]. Another study from India assessed the feasibility of cervical ultrasound to detect cervical spine fractures in children [14]. Hand-carried ultrasound has been successfully used for surgical patient selection across a broad spectrum of diseases, such as abdominal tumours and congenital malformations, as well as for telemedicine-guided diagnosis in rural areas [15–17].

Echocardiography using portable ultrasound devices in LMIC

The role of screening echocardiograms using a hand-carried ultrasound device has been studied in several countries. Kobal *et al.* report that they were able to screen or diagnose patients in rural Mexico referred for a cardiology evaluation with a hand-carried ultrasound device, obviating the need for a comprehensive echocardiogram

Table 1 Overview of the included studies

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Agrawal	2015	Assessment of ultrasound as a diagnostic modality for detecting potentially unstable cervical spine fractures in pediatric severe traumatic brain injury: A feasibility study	Journal of Pediatric Neurosciences	Original research	MicroMaxx	India	Hospital	Cervical ultrasound was used to emergently evaluate for, and detect, cervical spine fractures and ligamentous injuries in children with traumatic brain injury.
Beaton	2014	The utility of handheld echocardiography for early diagnosis of rheumatic heart disease	Journal of the American Society of Echocardiography	Original research	Vscan	Uganda	Field use/screening	Hand-held echocardiography for the screening of RHD proved to have 90% sensitivity and 93% specificity for detecting disease in 125 children.
Beaton	2015	The utility of handheld echocardiography for early rheumatic heart disease diagnosis: a field study	European Heart Journal – Cardiovascular Imaging	Original research	Vscan	Uganda	Field use/screening	In this study of 1420 children, hand-held echocardiography was able to detect RHD with 79% sensitivity and 87% specificity, with 98% sensitivity for detecting definite RHD.
Blaivas	2005	Change in differential diagnosis and patient management with the use of portable ultrasound in a remote setting	Wilderness & Environmental Medicine	Original research	Sonosite 180 Plus	Amazon	Field use/screening	Out of 25 scans that were performed in this study, portable ultrasound significantly altered disposition and treatment plans in 7 patients. Findings included intra-abdominal haemorrhage, pregnancy complications, hepatobiliary and renal diseases.
Coskun	2012	Our new stethoscope in the emergency department: handheld ultrasound	Turkish Journal of Trauma & Emergency Surgery	Original research	Vscan	Turkey	Hospital	In this study, FAST exams using Vscans were performed on 216 patients to evaluate for intra-abdominal haemorrhage. The authors demonstrated a sensitivity of 89%, specificity of 978%, when compared to radiologist-performed scans using regular ultrasound machines.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Cox	2014	Practice of percutaneous needle autopsy: a descriptive study reporting experiences from Uganda	BMC Clinical Pathology	Original research	Vscan	Uganda	Hospital	In this study involving 191 cases, ultrasound-guided biopsies of the heart, liver, spleen and kidneys led to a true success rate of 72–100% compared with 56–99% for blind biopsies.
Dean	2008	The utility of handheld ultrasound in an austere medical setting in Guatemala after a natural disaster	American Journal of Disaster Medicine	Original research	Micromaxx	Guatemala	Hospital	Hand-held ultrasound was utilised in 99 patients with a variety of different acuity levels and clinical applications, and ruled in an emergent problem for 12% of patients while 42% were ruled out. Main findings included abscesses, pregnancy complications, hepatobiliary and renal diseases.
Gingrich	2013	Point-of-care ultrasound in a resource-limited setting: diagnosing intussusception	The Journal of Emergency Medicine	Case report	Sonosite 180 Plus	Haiti	Hospital	An emergency physician in Haiti was able to successfully diagnose intussusception using portable ultrasound.
Giusca	2011	Accuracy of handheld echocardiography for bedside diagnostic evaluation in a tertiary cardiology center: comparison with standard echocardiography	Echocardiography	Original research	Acuson P10	Romania	Hospital	In this study, hand-held echocardiography was performed by trainees on 56 patients and compared against standard exams by experts with good agreement in evaluating left ventricular chamber and wall dimensions, left ventricular function and valve abnormalities.
Godown	2015	Handheld echocardiography *vs.* auscultation for detection of rheumatic heart disease	Pediatrics	Original research	VScan	Uganda	Field use/screening	In a study of 1317 children who were screened for RHD with hand-held ultrasound *vs.* auscultation, sensitivity for definite RHD was 98% *vs.* 22%.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Goksu	2014	Traumatic pseudoaneurysm and arteriovenous fistula detected by bedside ultrasound	The Journal of Emergency Medicine	Case report	Micromaxx	Turkey	Hospital	Hand-held ultrasound was used to successfully diagnose a new thigh bruit as a pseudoaneurysm with concomitant arteriovenous fistula in a 31-year-old trauma victim.
Harris	2015	Utility of compact ultrasound in a mass surgical selection program in Africa: experience of a sonologist at the MV Africa Mercy Hospital Ship's screening day	Journal of Ultrasound in Medicine	Original research	Titan	Republic of Congo	Field use/screening	Ultrasound was shown to be helpful in 14 of 20 patients undergoing surgical screening, eliminating the need for CT scans in pre-operative planning. Diagnoses included soft tissue mass, congenital abnormalities, ovarian tumour and breast cysts.
Hu	2014	Streamlined focused assessment with sonography for mass casualty prehospital triage of blunt torso trauma patients	American Journal of Emergency Medicine	Case report	Vscan	China	Field use/screening	FAST scans using hand-held ultrasound were used to triage 45 patients with non-ambulatory blunt torso trauma and demonstrated higher sensitivity and specificity when compared with established triage methods. Diagnoses made included intra-abdominal haemorrhage, pericardial effusions, pneumothoraces and volume status assessments.
Kirkpatrick	2013	Enabling the mission through trans-atlantic remote mentored musculoskeletal ultrasound: case report of a portable hand-carried tele-ultrasound system for medical relief missions	Telemedicine Journal and E-health	Case report	Nanomaxx	Togo	Field use/screening	Tele-ultrasound was used to guide a patient in West Africa through self-imaging techniques to diagnose a torn adductor muscle.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Kobal	2004	Hand-Carried Cardiac Ultrasound enhances healthcare delivery in developing countries	The American Journal of Cardiology	Original research	OptiGo	Mexico	Field use/screening	In this study of 126 patients, hand-carried cardiac ultrasound eliminated the need for further echocardiography in 90% of patients. Diagnoses included valvular diseases, left ventricular hypertrophy and systolic dysfunction.
Kobal	2004	Making an impossible mission possible	Chest	Original research	SonoHeart Elite	Gambia	Field use/screening	Hand-carried ultrasound was used to examine 1997 people and of those patients with hypertension, ultrasonography identified left ventricular hypertrophy in 65%.
Lu	2015	Simplified rheumatic heart disease screening criteria for handheld echocardiography	Journal of the American Society of Echocardiography	Original research	Vscan	Uganda	Field use/screening	In a study consisting of 1439 children, hand-held echocardiography demonstrated 98% sensitivity for detection of definite RHD with the ability to decrease the need for standard echocardiography by up to 80%.
Mancuso	2015	Focused cardiac ultrasound using a pocket-size device in the emergency room	Arquivos Brasileiros de Cardiologia	Original research	Vscan	Brazil	Hospital	Hand-held ultrasound used in the evaluation of 100 patients with cardiopulmonary complaints confirmed the diagnosis of several potentially life-threatening conditions and changed the diagnosis in 17 cases. Findings included heart failure, pulmonary embolism, pericardial effusion with tamponade, pericarditis, aortic stenosis and thoracic aortic dissection.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Mand	2003	Animated documentation of the filaria dance sign (FDS) in bancroftian filariasis	Filaria Journal	Original research	Sonosite 180 Plus	Ghana	Field use/screening	Hand-carried ultrasound was used to identify the unique movements (filarial dance sign) of *Wuchereria bancrofti* worms in scrotal lymphatic vessels in all 33 patients evaluated.
Meena	2013	Spontaneous migration of bullet from arm to forearm and its ultrasound guided removal	Journal of Ultrasound	Case report	Micromaxx	India	Hospital	Ultrasound was used to localise and remove a bullet in a 24-year-old man which had spontaneously migrated over a 3-month period from his proximal arm to his forearm.
Michels	2013	The predictive diagnostic value of serial daily bedside ultrasonography for severe dengue in Indonesian adults	PLoS Neglected Tropical Diseases	Original research	Signos	Indonesia	Hospital	Daily bedside ultrasound for pleural effusion, ascites and gallbladder wall thickening, performed on 66 patients with dengue fever, was better at predicting progression to severe disease when compared with monitoring of existing markers, such as haematocrit.
Murphy	2011	Ultrasound findings in *Plasmodium falciparum* malaria: A pilot study	Pediatric Critical Care Medicine	Original research	Micromaxx	Uganda	Hospital	Sonographic evaluation of optic nerve sheath diameter, transcranial Doppler, spleen size and cardiac function allowed for an improved assessment of 33 children with malaria.
Parashar	2011	Pocket carried ultrasound: its usefulness in clinical practice – a pilot study	Indian Heart Journal	Original research	Vscan	India	Hospital	In this study of 61 patients, hand-carried ultrasound was able to correctly identify a variety of normal and diseased cardiac anatomy, but most importantly identified valvular disease and ischaemia-related RWMA.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Presley	2013	Emergency department bedside ultrasound diagnosis of retinoblastoma in a child	Pediatric Emergency Care	Case report	Nanomaxx	Haiti	Hospital	Ultrasound was used to correctly diagnose retinoblastoma in a 30-month-old patient based on characteristic findings of bilateral ocular masses and dense calcifications.
Rotte	2014	Use of ultrasound to diagnose and manage a five-liter empyema in a rural clinic in sierra Leone	Case Reports in Emergency Medicine	Case report	Titan	Sierra Leone	Field use/screening	This report demonstrates the utility of ultrasound in the diagnosis and management of a dyspnoeic patient found to have a five-litre pleural empyema.
Samanta	2013	Cardiopulmonary resuscitation in undiagnosed situs inversus totalis in emergency department: An intensivist challenge	Saudi Journal of Anaesthesia	Case report	Micromaxx	India	Hospital	Ultrasonography was used during CPR on a 34-year-old woman with previously undiagnosed situs inversus totalis allowing for a modified approach to her resuscitation.
Sethi	2014	Point-of-care ultrasonography for position of tip of endotracheal tube in neonates	Indian Pediatrics	Original research	Micromaxx	India	Hospital	In this study, ultrasonography was able to visualise correct placement of endotracheal tube in 48 of 53 neonates and in the remaining 5 patients without visualisation, the tube was verified by X-ray to be at a higher level.
Shah	2010	Impact of portable ultrasound in trauma care after the Haitian earthquake of 2010	American Journal of Disaster Medicine	Original research	Micromaxx	Haiti	Hospital	Portable ultrasound was found to be useful in the evaluation of 142 patients after an earthquake, diagnosing intra-abdominal haemorrhage, pneumothorax and intra-abdominal infections. It also proved useful for ultrasound-guided regional anaesthesia.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Shorter	2012	Portable handheld ultrasound in austere environments: use in the Haiti disaster	Pre-hospital and disaster Medicine	Original research	Signos	Haiti	Field use/screening	Ultrasound was used in the triage of 50 patients and was found to influence decisions about patient care in 70% of scans by evaluating truncal trauma, fractures, foreign bodies, hepatobiliary and renal disease and pregnancy complications.
Singh	2013	American Society of Echocardiography: Remote Echocardiography with Web-Based Assessments for Referrals at a Distance (ASE-REWARD) Study	Journal of the American Society of Echocardiography	Original research	Vscan	India	Field use/screening	This study demonstrated the feasibility of remote, web-based evaluation by physicians across the world of 1021 echocardiography scans performed by sonographers in India who diagnosed valvular disease, systolic dysfunction and congenital heart disease.
Siqueira	2015	Training Program for Cardiology Residents to Perform Focused Cardiac Ultrasound Examination with Portable Device	Echocardiography	Original research	SonoHeart Elite, Nanomaxx	Brazil	Hospital	In this study, resident physicians were trained in focused cardiac ultrasound using hand-held devices with good agreement when compared with expert echocardiogaphers when diagnosing valvular disease, left ventricular hypertrophy, systolic dysfunction and pericardial effusion.
Stolz	2013	Intussusception detected with ultrasound in a resource-limited setting	Lancet	Case report	Micromaxx	Uganda	Hospital	Ultrasound was used to diagnose intussusception in a 5-month-old child based on characteristic findings of intra-abdominal free fluid, intestinal obstruction and target sign.

Table 1 (*Continued*)

First author	Year published	Title	Journal	Type of article	Ultrasound device used	Geographical region	Environment	Key findings
Sutherasan	2013	Predicting laryngeal edema in intubated patients by portable intensive care unit ultrasound	Journal of Critical Care	Original research	M-Turbo	Thailand	Hospital	Ultrasound was found to be useful in predicting laryngeal oedema in intubated patients by measuring air column width differences, with an NPV of 0.92.
Tsutsui	2004	Hand-carried ultrasound performed at bedside in cardiology inpatient setting – a comparative study with comprehensive echocardiography	Cardiovascular Ultrasound	Original research	OptiGo	Brazil	Hospital	In this study, hand-carried ultrasound was found to have good agreement with comprehensive echocardiography in detecting RWMA, systolic dysfunction and valvular disease.
Zha	2015	Ultrasound diagnosis of malaria: examination of the spleen, liver, and optic nerve sheath diameter	World Journal of Emergency Medicine	Original research	Nanomaxx	Tanzania	Hospital	This study demonstrated a specificity of 91% for spleen size and 75% for liver size in the diagnosis of severe malaria, demonstrating the potential utility of ultrasound as a tool for triage and risk stratification.
Zhang	2014	Utility of point-of-care ultrasound in acute management triage of earthquake injury	American Journal of Emergency Medicine	Original research	Vscan	China	Field use/screening	In this study, 38 patients with blunt truncal trauma or open extremity injury were triaged using modified FAST exams with positive findings found in 45% of patients, such as intra-abdominal free fluid, pneumothorax or volume status assessments, directly affecting their management.

RHD, rheumatic heart disease; FAST, focused assessment with sonography for trauma; RWMA, regional wall motion abnormalities.

in 90% of patients seen [18]. A similar approach was used to diagnose patients with left ventricular hypertrophy (LVH) [19]. The presence of LVH was used as an indicator to initiate antihypertensive therapy. Multiple studies demonstrate the successful use of hand-held ultrasound to screen for rheumatic heart disease, where it appears to be clearly superior to auscultation alone [20–23]. Echocardiograms performed using a hand-held ultrasound device in emergency department patients with suspected cardiac complaints in Brazil helped to confirm or change the diagnosis in half of all cases, mostly ruling out heart failure and cardiogenic shock, but also diagnosing pericarditis as cause of chest pain [24]. Two studies from Brazil demonstrate high diagnostic accuracy of hand-carried ultrasound compared to comprehensive echocardiograms when assessing ejection fraction, wall motion, and valvular regurgitation in cardiac in-patients, and acquisition of diagnostic skills was reported to be good even with limited training [25, 26]. Similarly, researchers from Romania report that cardiology trainees using a hand-held ultrasound device accurately identified valvular abnormalities, pericardial effusion and abnormal left ventricular chamber morphology [27]. Parashar *et al.* describe their experiences with a hand-held ultrasound device in diagnosing a wide variety of cardiac problems, in particular valvular abnormalities and ischaemia-related regional wall motion abnormalities [28].

Ultrasound protocols used in LMIC and impact of portable ultrasound on patient management

Besides echocardiography, only few publications have assessed the application of ultrasound-based clinical algorithms and protocols for disease processes commonly encountered in LMIC. Zha *et al.* developed a risk stratification protocol for malaria in an endemic area, using measurements of spleen, liver and optic nerve sheath diameter by a hand-held ultrasound device [29]. Murphy *et al.* describe a similar protocol, using optic nerve sheath diameter, echocardiogram, spleen size and transcranial Doppler measurements [30]. Mand *et al.* propose the use of scrotal ultrasound to help in the assessment of lymphatic filariasis [31]. Cox *et al.* developed a protocol using hand-held ultrasound to guide needle biopsy autopsies, which had superior success rates to landmark-guided needle biopsy [32]. Michels *et al.* used a hand-held ultrasound device for daily serial exams of patients with dengue, evaluating them for evidence of subclinical plasma leakage by screening for pleural effusion, ascites and gallbladder wall thickening. They found these sonographic abnormalities to be more helpful in predicting progression to severe dengue than using laboratory markers such as haematocrit. Gallbladder wall thickening was particularly helpful, yielding a negative predictive value for severe dengue of 91% [33]. Hand-carried ultrasound was successfully used to confirm the position of an endotracheal tube in neonates in a rural hospital India, with the potential to obviate the need for radiographic confirmation [34]. A study from Thailand reports on the use of hand-carried ultrasound to assess laryngeal oedema in patients being evaluated for extubation readiness [35].

Blavais *et al.* report on the use of a hand-carried ultrasound machine in the Amazon jungle [36]. They found that ultrasound use had a significant impact on patient disposition, aiding both in determining the need for rapid evacuation as well as providing reassurance that local treatment would be safe. Most scans involved abdominal and pelvic applications. A hand-held ultrasound device was used for Focused Assessment with Sonography for Trauma (FAST) examinations in Turkey, and compared well to follow-up examinations carried out by radiologists using full-size machines [37].

Portable ultrasound use in disaster situations

Natural disasters, like earthquakes, are particularly challenging to manage in LMIC with limited healthcare resources at baseline. The lack of reliable access to power, a high number of victims and the need for rapid triage make ultrasound a frequently used tool in these scenarios. In all studies identified, patients were evaluated by modified FAST examinations, supplemented with pulmonary, pelvic and soft tissue scans. Shorter *et al.* report using a hand-held ultrasound device in the aftermath of the 2010 earthquake in Haiti. Ultrasound changed the clinical management in 70% of patients evaluated, such as surgical referral, clinical observation instead of previously planned surgery, decisions about transfer to a higher level of care or use of certain medications [38]. Shah *et al.* report on the usefulness of a hand-carried ultrasound device in triaging and treating crush injury victims in Haiti [39]. After a hurricane and mudslide in Guatemala in 2005, a hand-carried ultrasound machine was deployed. A total of 137 scans were performed in 10 days, and almost nine of ten scans required a curved array probe [40]. A hand-held ultrasound device was also successfully used to modify an established triage algorithm for rapid assessment with FAST examination after an earthquake in China [41]. Another report from China illustrates the immediate impact of ultrasound-guided assessment on the initial resuscitation of earthquake victims [42]. Given the degree of traumatic injuries seen after natural disasters, the most common sonographic evaluations performed in these studies aimed at

diagnosing intra-abdominal haemorrhage and pneumothoraces. In addition, a significant number of scans was carried out to evaluate pregnancy complications, musculoskeletal injuries or hepatobiliary disease.

Characteristics of different portable ultrasound devices

Table 2 lists all currently commercially available hand-held or hand-carried ultrasound systems. This overview includes all devices discussed in the studies that are included in this review. All systems typically have some form of integration with imaging storage and management systems, as well as internal storage for images, video clips, voice and text annotations. As these features are less used in the environments described in this article, they are excluded from the table to improve clarity.

Discussion

Ultrasound appears to be the ideal imaging modality at the bedside as no other imaging technology requires as little infrastructure and maintenance as ultrasound. Ultrasound gel, the only routine supply item needed, can easily be produced locally [43]. Based on previous data, ultrasound has been categorised as 'essential' for better patient care in LMIC [44]. Hence, we assessed the available scientific literature to provide an update on the current situation of hand-carried and hand-held ultrasound devices in LMIC.

Our systematic literature review reveals that hand-carried and hand-held ultrasound devices are used for a variety of different indications. In particular, these devices appear to be frequently used for echocardiographic applications and in disaster situations. Attempts have also been made to formally define their indication for use by including ultrasound in patient care protocols. The most commonly reported geographical area of use in LMIC is sub-Saharan Africa. Data assessing the resulting impact of ultrasound findings on patient management are scarce, but in this review portable ultrasound led to a modification of clinical management in up to 70% of reported cases [38, 45]. The technical features and specifications of the devices used vary widely with regard to imaging modes and screen size.

Our search resulted mainly in original research articles, although mostly representing observational data from case series. The overall level of evidence is low, and high-quality, objective studies analysing the use and impact of hand-carried and hand-held ultrasound devices are needed to better inform key stakeholders and policy makers. Despite previous calls for more rigorous studies on the impact of portable ultrasound devices, there has been a lack of funding to support these efforts [46]. However, high-quality data are urgently needed to assess the longitudinal impact of readily available, bedside ultrasound diagnosis and treatment in LMIC. Indeed, ultrasound could be of particular relevance in these settings, because several neglected tropical diseases are endemic in LMIC for which international guidelines highly recommend the use of ultrasound imaging, for example echinococcosis and schistosomiasis [47–49]. Likewise, the utility of hand-held devices for improved diagnosis and clinical patient management in LMIC has already been reported for other specific diagnostic areas, for example hand-held, battery-run microscopes for the diagnosis of intestinal parasites in settings without laboratory infrastructure and with no constant access to electricity [50–52].

Anecdotally, the authors themselves have employed hand-carried ultrasound devices, and the hand-held GE Vscan Dual (General Electric, Fairfield, CT, USA), in LMIC. We have successfully diagnosed and managed increased intracranial pressure, ocular trauma, pneumothorax, pneumonia, pleural effusion, pulmonary oedema, systolic congestive heart failure, urinary retention, liver cysts, deep vein thrombosis in these settings, where alternative imaging options were either not available altogether, or not without significant delays in patient care.

One important drawback to the successful broad implementation of ultrasound-based diagnostics in LMIC is the lack of training in the majority of resource-constrained settings. In fact, there often is little to no formal training for practising physicians [53]. Lack of qualified clinicians able to provide ultrasound training has been identified as one of the major barriers that need to be addressed before a wider use of ultrasound imaging seems feasible [4]. However, it has been shown that even short-training courses may lead to significant knowledge retention and improve practical skills, even when prior ultrasound experience was minimal [54–57]. An international initiative led by the University of Pavia in Italy is now addressing the pressing need for improved training regarding ultrasound application in the tropics through the implementation of regular, expert-led short-term training courses (http://www.tropicalultrasound.org), but further funding for implementation of such programmes in LMIC is urgently required. There are also other initiatives with a similar focus (http://www.pureultrasound.org).

While a number of portable ultrasound devices have been commercialised, not all are truly hand-held, as demonstrated in Table 2. The literature suggests that a curved array probe is sufficient for the vast majority of examination indications, which are mostly of abdominal and obstetric nature [40, 44–46]. These findings may help

Table 2 Technology review of commercially available hand-held (HH) and hand-carried (HC) ultrasound systems (Cart-based systems and larger were excluded)

Device	Format	Console dimensions (cm)/Weight (kg)	Battery-capacity (Ah)/run time (h)	Probes	Other imaging modes	Screen size/Resolution
GE						
VScan	HH	13.5 × 7.3 × 2.8/0.4	Li-po 1.4/1.0	1× PA (fixed sector)	CD	3.5″/240 × 320
VScan Dual	HH	13.5 × 7.3 × 2.8/0.4	Li-po 1.4/1.0	1× dual PA (fixed linear + sector)	CD	3.5″/240 × 320
Venue 40	HC	28.2 × 27.4 × 5.6/3.6	Li-ion 5.0/1.0	1× PA (standard + EC)	NR, PD, CD, M	10.4″/800 × 600
Sonosite						
NanoMaxx	HH	20.8 × 35.8 × 5.8/2.7	Li-ion 5.2/2.0	1× PA (standard)	M, CD, PD	8.4″/*
Sonosite180/ SonoHeart Elite	HC	33.8 × 19.3 × 6.4/2.5	Li-ion 3.0/1.5–4.0	1× PA (standard + EC)	CD, PD, PW, CW, M, H	5.0″/*
Micromaxx	HC	30.0 × 27.4 × 7.9/3.9	Li-ion 4.4/2.0	1× PA (standard + EC + TEE)	H, M, CD, PD, PW, CW	10.4″/*
M-Turbo	HC	30.0 × 27.4 × 7.9/3.9	Li-ion 5.2/2.0	1× PA (standard + EC + TEE)	H, M, CD, PD, PW, CW	10.4″/*
Edge	HC	32.7 × 31.5 × 6.4/3.9	Li-ion */2.0	1× PA (standard + EC + TEE)	H, M, CD, PD, PW, CW	12.1″/*
Titan	HC	30.0 × 27.7 × 7.6/3.8	Li-ion 4.4/1.5–4.0	1× PA (standard + EC)	H, M, CD, PD, PW, CW	8.5″/*
Siemens						
Acuson P10	HH	5.4 × 9.7 × 14.2/0.73	Li-ion */1.0	1× PA (fixed sector)	H	3.7″/640 × 480
Phillips						
Visiq	HHT	~10″ tablet (from photos)	*/2.5	1× PA (curvi-linear)	H, M, PW, CD	~10″ tablet/*
OptiGo	HC	33 × 22.9 × 8.9/3.4	Li-ion 7.2/2	1× PA (fixed sector)	CD	6.5″/640 × 480
Mobisante						
Mobi-US SP1	HH	13.0 × 7.0 × 1.0/0.33	*/1–5.5	1× MW (sector)	–	4.1″/800 × 480
Mobi-US TC2	HC	25.2 × 19.3 × 1.5/3.2	*/2.25	1× MW (standard + EC)	–	10″/1024 × 768
Signostics						
SignosRT	HH	11.5 × 6.8 × 2/0.4	Li-po 2.0/2–30	1× MW (fixed sector)	M, PW	2.7″/240 × 320
Terrason						
uSmart 3200T	HC	32.1 × 22.4 × 3.2/2.0	*/*	1× PA (standard + EC)	M, CD, PW, PD	11.5″/*

NR, needle recognition; PD, power Doppler; CD, colour Doppler; M, M-mode; PW, pulsed-wave Doppler; CW, continuous-wave Doppler; Z, zoom; H, Harmonic imaging; PA, phased-array; MW, mechanical wobbler; EC, endocavitary; TEE, transesophageal echo; HH, hand-held device (i.e. PDA/tablet); HC, hand-carried (i.e. laptop); li-po, lithium polymer battery; li-ion, lithium-ion battery.
* = unknown parameter.
B-mode imaging, zoom and measurement callipers were assumed as standard features for all systems.

manufacturers to design affordable, easy-to-use devices that focus on battery life and rugged design rather than on multiple transducer probes.

Our review has several limitations. First, we may have missed reports from small journals published in LMIC, as these are often not included in the literature databases searched for this review. This is particularly true for scientific journals that are not published in English. For instance, it is likely that many researchers from non-English speaking LMIC prefer to submit manuscripts to journals that are published in the regionally most important language, such as French (West and Central Africa), Spanish (Latin America) or Portuguese (Brazil). Such a publication bias may partially explain why most manuscripts reviewed here have been written by authors from high-income countries. Second, the lack of well-designed studies that assess the utility and clinical impact of hand-held and hand-carried ultrasound devices limits the validity of our conclusion. Specifically, the reported data on the impact of portable ultrasound clinical management are likely overestimating its true effect, as it is commonly seen with observational studies [58].

In summary, this review highlights the potential for portable ultrasound devices in LMIC, and hand-held machines in particular. However, so far the lack of sufficient data pertaining to the role of portable ultrasound systems for improved management of certain clinical syndromes does not allow for general practice recommendations. We conclude that there is a need to scientifically assess and evaluate the use of these devices in LMIC at a large scale to better define the scope, impact and potential benefits of hand-carried ultrasound in resource-constrained settings worldwide.

Acknowledgement

We thank Gurpreet K. Rana, MLIS, Global Health Coordinator, Taubman Health Sciences Library, University of Michigan, for her assistance with the literature search.

References

1. Moore CL, Copel JA. Point-of-care ultrasonography. *N Engl J Med* 2011: **364**: 749–757.
2. World Health Organization. Future use of new imaging technologies in developing countries. Report of a WHO Scientific Group. *World Health Organ Tech Rep Ser* 1985: **723**: 1–67.
3. Nelson BP, Narula J. How relevant is point-of-care ultrasound in LMIC? *Glob Heart* 2013: **8**: 287–288.
4. Henwood PC, Beversluis D, Genthon AA *et al.* Characterizing the limited use of point-of-care ultrasound in Colombian emergency medicine residencies. *Int J Emerg Med* 2014: **7**: 7.
5. Wright J, Noriega O, Ho H. The application of hand-held ultrasound scanner in teaching of telemedicine and rural medicine. *Donald School J Ultrasound Obstet Gynecol* 2014: **8**: 87–91.
6. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Ann Intern Med* 2009: **151**: 264–269, W264.
7. Rotte M, Fields JM, Torres S, Dominick C, Kelly JD. Use of ultrasound to diagnose and manage a five-liter empyema in a rural clinic in Sierra Leone. *Case Rep Emerg Med* 2014: **2014**: 173810.
8. Gingrich AS, Saul T, Lewiss RE. Point-of-care ultrasound in a resource-limited setting: diagnosing intussusception. *J Emerg Med* 2013: **45**: e67–e70.
9. Stolz LA, Kizza H, Little K, Kasekende J. Intussusception detected with ultrasound in a resource-limited setting. *Lancet* 2013: **381**: 2054.
10. Goksu E, Yuruktumen A, Kaya H. Traumatic pseudoaneurysm and arteriovenous fistula detected by bedside ultrasound. *J Emerg Med* 2014: **46**: 667–669.
11. Presley BC, Flannigan MJ. Emergency department bedside ultrasound diagnosis of retinoblastoma in a child. *Pediatr Emerg Care* 2013: **29**: 1128–1131.
12. Meena S, Singla A, Saini P, Mittal S, Chowdhary B. Spontaneous migration of bullet from arm to forearm and its ultrasound guided removal. *J Ultrasound* 2013: **16**: 223–225.
13. Samanta S, Ghatak T. Cardiopulmonary resuscitation in undiagnosed situs inversus totalis in emergency department: an intensivist challenge. *Saudi J Anaesth* 2013: **7**: 347–349.
14. Agrawal D, Sinha TP, Bhoi S. Assessment of ultrasound as a diagnostic modality for detecting potentially unstable cervical spine fractures in pediatric severe traumatic brain injury: a feasibility study. *J Pediatr Neurosci* 2015: **10**: 119–122.
15. Kirkpatrick AW, Blaivas M, Sargsyan AE *et al.* Enabling the mission through trans-atlantic remote mentored musculoskeletal ultrasound: case report of a portable hand-carried tele-ultrasound system for medical relief missions. *Telemed J E Health* 2013: **19**: 530–534.
16. Harris RD, Parker G. Utility of compact ultrasound in a mass surgical selection program in Africa: experience of a sonologist at the MV Africa Mercy Hospital Ship's screening day. *J Ultrasound Med* 2015: **34**: 341–348.
17. Singh S, Bansal M, Maheshwari P *et al.* American Society of Echocardiography: remote echocardiography with web-based assessments for referrals at a distance (ASE-REWARD) study. *J Am Soc Echocardiogr* 2013: **26**: 221–233.
18. Kobal SL, Lee SS, Willner R *et al.* Hand-carried cardiac ultrasound enhances healthcare delivery in developing countries. *Am J Cardiol* 2004: **94**: 539–541.
19. Kobal SL, Czer LS, Czer PC, Feldsher Z, Hamilton R, Siegel RJ. Making an impossible mission possible. *Chest* 2004: **125**: 293–296.

20. Godown J, Lu JC, Beaton A *et al.* Handheld echocardiography versus auscultation for detection of rheumatic heart disease. *Pediatrics* 2015: **135**: e939–e944.
21. Lu JC, Sable C, Ensing GJ *et al.* Simplified rheumatic heart disease screening criteria for handheld echocardiography. *J Am Soc Echocardiogr* 2015: **28**: 463–469.
22. Beaton A, Aliku T, Okello E *et al.* The utility of handheld echocardiography for early diagnosis of rheumatic heart disease. *J Am Soc Echocardiogr* 2014: **27**: 42–49.
23. Beaton A, Lu JC, Aliku T *et al.* The utility of handheld echocardiography for early rheumatic heart disease diagnosis: a field study. *Eur Heart J Cardiovasc Imaging* 2015: **16**: 475–482.
24. Mancuso FJ, Siqueira VN, Moises VA *et al.* Focused cardiac ultrasound using a pocket-size device in the emergency room. *Arq Bras Cardiol* 2014: **103**: 530–537.
25. Tsutsui JM, Maciel RR, Costa JM, Andrade JL, Ramires JF, Mathias W Jr. Hand-carried ultrasound performed at bedside in cardiology inpatient setting – a comparative study with comprehensive echocardiography. *Cardiovasc Ultrasound* 2004: **2**: 24.
26. Siqueira VN, Mancuso FJ, Campos O, De Paola AA, Carvalho AC, Moises VA. Training program for cardiology residents to perform focused cardiac ultrasound examination with portable device. *Echocardiography* 2015: **32**: 1455–1462.
27. Giusca S, Jurcut R, Ticulescu R *et al.* Accuracy of handheld echocardiography for bedside diagnostic evaluation in a tertiary cardiology center: comparison with standard echocardiography. *Echocardiography* 2011: **28**: 136–141.
28. Parashar SK, Jain V. Pocket carried ultrasound: its usefulness in clinical practice–a pilot study. *Indian Heart J* 2011: **63**: 185–189.
29. Zha Y, Zhou M, Hari A *et al.* Ultrasound diagnosis of malaria: examination of the spleen, liver, and optic nerve sheath diameter. *World J Emerg Med* 2015: **6**: 10–15.
30. Murphy S, Cserti-Gazdewich C, Dhabangi A *et al.* Ultrasound findings in *Plasmodium falciparum* malaria: a pilot study. *Pediatr Crit Care Med* 2011: **12**: e58–e63.
31. Mand S, Marfo-Debrekyei Y, Dittrich M, Fischer K, Adjei O, Hoerauf A. Animated documentation of the filaria dance sign (FDS) in bancroftian filariasis. *Filaria J* 2003: **2**: 3.
32. Cox JA, Lukande RL, Kalungi S *et al.* Practice of percutaneous needle autopsy; a descriptive study reporting experiences from Uganda. *BMC Clin Pathol* 2014: **14**: 44.
33. Michels M, Sumardi U, de Mast Q *et al.* The predictive diagnostic value of serial daily bedside ultrasonography for severe dengue in Indonesian adults. *PLoS Negl Trop Dis* 2013: **7**: e2277.
34. Sethi A, Nimbalkar A, Patel D, Kungwani A, Nimbalkar S. Point of care ultrasonography for position of tip of endotracheal tube in neonates. *Indian Pediatr* 2014: **51**: 119–121.
35. Sutherasan Y, Theerawit P, Hongphanut T, Kiatboonsri C, Kiatboonsri S. Predicting laryngeal edema in intubated patients by portable intensive care unit ultrasound. *J Crit Care* 2013: **28**: 675–680.
36. Blaivas M, Kuhn W, Reynolds B, Brannam L. Change in differential diagnosis and patient management with the use of portable ultrasound in a remote setting. *Wilderness Environ Med* 2005: **16**: 38–41.
37. Coskun F, Akinci E, Ceyhan MA, Sahin Kavakli H. Our new stethoscope in the emergency department: handheld ultrasound. *Ulus Travma Acil Cerrahi Derg* 2011: **17**: 488–492.
38. Shorter M, Macias DJ. Portable handheld ultrasound in austere environments: use in the Haiti disaster. *Prehosp Disaster Med* 2012: **27**: 172–177.
39. Shah S, Dalal A, Smith RM, Joseph G, Rogers S, Dyer GS. Impact of portable ultrasound in trauma care after the Haitian earthquake of 2010. *Am J Emerg Med* 2010: **28**: 970–971.
40. Dean AJ, Ku BS, Zeserson EM. The utility of handheld ultrasound in an austere medical setting in Guatemala after a natural disaster. *Am J Disaster Med* 2007: **2**: 249–256.
41. Hu H, He Y, Zhang S, Cao Y. Streamlined focused assessment with sonography for mass casualty prehospital triage of blunt torso trauma patients. *Am J Emerg Med* 2014: **32**: 803–806.
42. Zhang S, Zhu D, Wan Z, Cao Y. Utility of point-of-care ultrasound in acute management triage of earthquake injury. *Am J Emerg Med* 2014: **32**: 92–95.
43. Binkowski A, Riguzzi C, Price D, Fahimi J. Evaluation of a cornstarch-based ultrasound gel alternative for low-resource settings. *J Emerg Med* 2014: **47**: e5–e9.
44. Groen RS, Leow JJ, Sadasivam V, Kushner AL. Review: indications for ultrasound use in low- and middle-income countries. *Trop Med Int Health* 2011: **16**: 1525–1535.
45. Kotlyar S, Moore CL. Assessing the utility of ultrasound in Liberia. *J Emerg Trauma Shock* 2008: **1**: 10–14.
46. Harris RD, Marks WM. Compact ultrasound for improving maternal and perinatal care in low-resource settings: review of the potential benefits, implementation challenges, and public health issues. *J Ultrasound Med* 2009: **28**: 1067–1076.
47. Hatz CF. The use of ultrasound in schistosomiasis. *Adv Parasitol* 2001: **48**: 225–284.
48. Utzinger J, Becker SL, Knopp S *et al.* Neglected tropical diseases: diagnosis, clinical management, treatment and control. *Swiss Med Wkly* 2012: **142**: w13727.
49. Brunetti E, Kern P, Vuitton DA. Expert consensus for the diagnosis and treatment of cystic and alveolar echinococcosis in humans. *Acta Trop* 2010: **114**: 1–16.
50. Bogoch II, Coulibaly JT, Andrews JR *et al.* Evaluation of portable microscopic devices for the diagnosis of Schistosoma and soil-transmitted helminth infection. *Parasitology* 2014: **141**: 1811–1818.
51. Bogoch II, Andrews JR, Speich B *et al.* Quantitative evaluation of a handheld light microscope for field diagnosis of soil-transmitted helminth infection. *Am J Trop Med Hyg* 2014: **91**: 1138–1141.

52. Ephraim RK, Duah E, Cybulski JS *et al.* Diagnosis of *Schistosoma haematobium* infection with a mobile phone-mounted foldscope and a reversed-lens cell scope in Ghana. *Am J Trop Med Hyg* 2015: **92**: 1253–1256.
53. LaGrone LN, Sadasivam V, Kushner AL, Groen RS. A review of training opportunities for ultrasonography in low and middle income countries. *Trop Med Int Health* 2012: **17**: 808–819.
54. Shah S, Noble VE, Umulisa I *et al.* Development of an ultrasound training curriculum in a limited resource international setting: successes and challenges of ultrasound training in rural Rwanda. *Int J Emerg Med* 2008: **1**: 193–196.
55. Shah SP, Epino H, Bukhman G *et al.* Impact of the introduction of ultrasound services in a limited resource setting: rural Rwanda 2008. *BMC Int Health Hum Rights* 2009: **9**: 4.
56. Adler D, Mgalula K, Price D, Taylor O. Introduction of a portable ultrasound unit into the health services of the Lugufu refugee camp, Kigoma District, Tanzania. *Int J Emerg Med* 2008: **1**: 261–266.
57. Shmueli H, Burstein Y, Sagy I *et al.* Briefly trained medical students can effectively identify rheumatic mitral valve injury using a hand-carried ultrasound. *Echocardiography* 2013: **30**: 621–626.
58. Odgaard-Jensen J, Vist GE, Timmer A *et al.* Randomisation to protect against selection bias in healthcare trials. *Cochrane Database Syst Rev* 2011: MR000012.

Corresponding Author **Torben K. Becker**, Department of Critical Care Medicine, University of Pittsburgh Medical Center, 3471 Fifth Avenue, Kaufmann Building, Pittsburgh, PA 15213, USA. E-mail: tbeckermd@gmail.com