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LITERATURE REVIEW

Ultrasound Use in Resource-limited Settings: A Systematic Review

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Abstract

Purpose: Over the past decade, ultrasound machines have become smaller, less expensive, more reliable, durable and user-friendly, making ultrasonography an ideal imaging modality in resource-poor settings. We conducted a literature review to examine the use of ultrasound in resource-limited settings, with emphasis on common applications, barriers to implementation, and impact on clinical decision-making and patient disposition.

Methods and Materials: Literature review. We conducted a PubMed and Cochrane Central search on the clinical use of ultrasound in the developing world. Search terms included ultrasonography, developing countries, resource limited, remote setting, poverty, and low income. Articles from 2000 to 2015 that included data on the clinical use of ultrasound in resource limited settings were eligible for inclusion. Data on country of origin, medical specialty, US modality, clinical impact, and potential barriers to implementation were recorded.

Results: Fifty-eight articles were eligible for inclusion. Most studies were observational, with Africa as the most common site, accounting for 35 articles. Radiology was the most represented specialty. Cardiac and obstetric were the most commonly utilized ultrasound modalities. Most data on cardiac ultrasound pertained to its role in the diagnosis of rheumatic heart disease. Obstetric ultrasound was primarily used for pregnancy dating and diagnosing fetal abnormalities. Twelve studies examined clinical impact of ultrasound in resource-limited settings and showed that its use dramatically altered differential diagnosis and patient disposition. Common barriers to implementation were the high cost of equipment and maintenance, and lack of skilled personnel and formal training programs. A commonly cited consequence of ultrasound use in resource-poor settings was sex-selective abortions.

Conclusion: Ultrasound has widespread clinical applications, particularly as a diagnostic tool in the developing world. Significant barriers exist with respect to access and training of US in resource-limited settings. Further research is needed to study its impact on medical decision-making, patient disposition and outcomes.

Introduction

Since its introduction in the 1960s, ultrasonography has been a valued diagnostic imaging modality across multiple clinical specialties, particularly radiology, cardiology and obstetrics/gynecology. In high-income countries, ultrasound (US) is generally affordable and readily available, with easy access to training programs for medical providers. However, in some low- and middle-income countries, diagnostic imaging is often very limited or completely lacking.

Over the past decade, US machines have become smaller, less expensive, more reliable, durable

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and user-friendly by non-physician providers, making ultrasonography an ideal imaging modality in resource-poor settings. Several studies have identified US as a useful tool in the evaluation of poverty-related diseases such as tuberculosis, malaria and dehydration due to diarrheal illnesses (1-4). Despite its widespread clinical utility in resource-poor settings, there still exist significant barriers to US access and training programs. Our objective was to review the literature regarding the use of ultrasound in resource-limited settings, with emphasis on common applications, clinical impact, barriers to implementation, US training programs and education, and consequences of its use.

Methods and materials

We conducted a PubMed and Cochrane Central search on the clinical use of ultrasound in the developing world (Figure 1). Search terms included: ultrasonography, developing countries, resource-limited, remote setting, poverty, and low-income. Original research articles, case reports, opinions and descriptive studies published in English between 2000 to 2015 that included data on the clinical use of ultrasound in resource-limited settings were eligible for inclusion. All articles were obtained and reviewed by the first author for inclusion into the review. The search was then expanded using the references of each article. Data on country of origin, medical specialty, US modality, clinical impact, barriers to implementation, US training programs and education, and consequences of its use were recorded. If the medical specialty was unclear, the department represented by the first author was used.

Results

Fifty-eight articles were eligible for inclusion, as shown in Table 1 (1-58). Of these articles, 45 (78%) were descriptive research articles, including 30 (52%) prospective, 9 (16%) cross-sectional, 4 (7%) retrospective, and 2 (3%) longitudinal research studies (Table 1). There were 3 (5%) case reports/series, 2 (3%) case-control studies, 4 (7%) expert opinions, and 3 (5%) controlled trials, two of which were randomized. Articles were identified from 29 different countries; Africa was the most common region, accounting for 35 (60%) articles, followed by 9 (16%) from Asia, 3 (5%) from South America, 3 (5%) from Central America, 3 (5%) USA, and 1 (2%) from the United Kingdom. The most common country represented was Uganda, with 7 (12%) articles, followed by 5 (9%) from Nigeria, and 3 (5%) from Rwanda, India, Tanzania, Pakistan, Ghana, and the United States. Radiology was the most common specialty with 16 (28%) articles, followed by 13 (22%) emergency medicine, 7 (12%) internal medicine, 7 (12%) cardiology, 6 (10%) obstetrics/gynecology, and 5 (9%) pediatrics. Cardiac ultrasound was the most common modality accounting for 13 (22%) articles, followed by 10 (17%) obstetric, 7 (12%) abdominal, and 2 (3%) trauma (Focused Assessment with Sonography in Trauma).

Twelve studies addressed clinical impact or change in clinical management using US in resource-limited settings, as shown in Table 2 (1,18,19,21,31,37,39,42,44,53-55). Generally, a change in clinical management referred to differing pre- and post-US diagnoses and/or changes in treatment or disposition after ultrasonography (18,21,39,53,55). Change in clinical management ranged from 7% to 62% (Table 2). Justice et al. reported a specificity of 99% for abdominal US in the detection of intussusception. Likewise, Smith et al. reported a 100% specificity for FAST in the detection of free fluid in trauma. Thirteen studies addressed US education and training programs (20,24,26,27,32,35,45,47,49,50,52,56).

Discussion

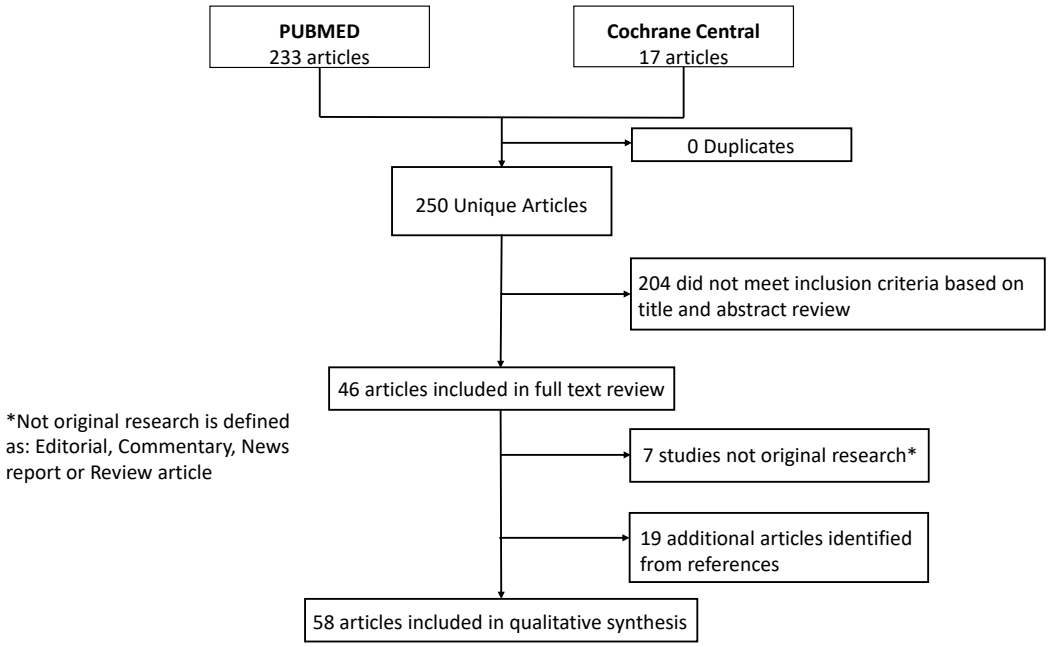
To our knowledge, this study represents the most complete review to date of the use of US in resource-limited settings. Among the 58 studies in this review, 10 different US modalities were represented with a variety of applications described below.

Cardiac Ultrasound

Cardiac failure is a major cause of morbidity and mortality worldwide. While coronary disease and hypertension are common etiologies in developed countries, underlying causes in the developing world may vary (59). Ismail et al. conducted a study to assess the underlying etiologies of cardiac failure in an adult population in southwestern Uganda using echocardiography, and found that the majority of cases (49%) are due to underlying cardiomyopathy, most commonly dilated cardiomyopathy (56%) and valvular heart disease (35%) (36). Sixteen percent of cardiomyopathy was restrictive, with only one documented case of endomyocardial fibrosis (EMF), which is a much lower prevalence than that documented in other parts of Uganda. Interestingly, Freers et al. report EMF as accounting for nearly 20% of cases of cardiac failure in central Uganda, suggesting major regional differences in the prevalence of this disease (60). A study by Maro et al. in Tanzania found a low prevalence (<1%) of EMF using echocardiography (43). Additionally, in the absence of echocardiography, only 21% of their patient population had a correct clinical diagnosis, leaving 79% of patients at risk of misdiagnoses and potentially expensive and risky treatment options (43).

Of the 13 studies using cardiac ultrasound, 7 evaluated its use in the diagnosis of rheumatic heart disease (RHD). RHD is the most common acquired heart disease in children in many countries of the developing world and poses a significant public health risk, with an estimated 15 million cases worldwide, 282,000 new cases and 233,000 deaths annually (61). Colquhoun et al. used echocardiography to determine the prevalence of RHD in school children in Fiji and found a prevalence of 7.2 cases per 1000 persons (25). They also reported a 97% specificity using echo in the setting of a pathological murmur in the diagnosis on RHD. Rossi et al., in a study evaluating the prevalence of RHD in high school children of Eritrea using echo, found a high prevalence of 4% (51). Only 51% of students with diagnosed RHD had a murmur on exam, demonstrating the importance of both clinical and US surveillance in the diagnosis of RHD. Godown

Figure 1. Flow chart of literature review process.



et al., in a study of handheld echo versus auscultation in the detection of RHD in Uganda, showed that sensitivity was significantly improved using handheld echo (98% vs 22%) (31). Similarly, Beaton et al., in an evaluation of handheld echo in the diagnosis of subclinical RHD in Uganda, reported a 90% sensitivity and 93% specificity for the diagnosis of RHD (15). Overall prevalence of RHD in their study was 33%. Of the cases of valvular heart disease seen by Ismail et al., 30% showed echocardiographic features of rheumatic valvular disease (36).

Other reported uses of cardiac ultrasound in the developing world include assessment of hemodynamics in severe dehydration (1,4). Levine et al. evaluated two ultrasound measures of severe dehydration in children of Rwanda with diarrhea and/or vomiting (1). They reported a sensitivity and specificity of 93% and 59%, respectively, for the aorta to IVC ratio, and 93% and 35%, respectively, for IVC inspiratory collapse. The World Health Organization Dehydration Scale had a much lower sensitivity at 73% (1). Yacoub et al. used portable echo to evaluate cardiac function and hemodynamic status of children in Kenya admitted with severe malaria (4). They found that children with severe malaria and metabolic acidosis had evidence of hypovolemia indicated by a higher IVC collapsibility index and cardiac dysfunction, with higher left myocardial performance index.

Obstetric/Gynecologic Ultrasound

In many developing countries, there is poor access to antenatal care and screening. Bawa et al. report 2 cases of fetal malrotation in India, with very different outcomes based on the availability of antenatal scanning (14). In one case, the mother had a third trimester US which detected malrotation and aided in saving the baby's life, while in the second case, the mother had no access to antenatal screening resulting in progression of malrotation to midgut volvulus and its sequelae. Geerts et al. evaluated the impact of US dating on obstetric services, referrals and pregnancy outcomes in two midwife obstetric units in South Africa (30). US did not alter pregnancy outcomes but reduced the number of pre-term labors/rupture of membranes (12.0% vs 16.7%, P<0.003), post-term deliveries (8.1% vs 10.8%, P<0.04) and referrals to a regional center for fetal surveillance (15.9% vs 29.6%, P<0.00).

In a study of US utility in Liberia, Kotlyar et al. found that OB/GYN was the most common indication (53%), primarily in the evaluation of first trimester vaginal bleeding/abdominal pain, fetal demise, estimation of gestational age, multiple gestation, and emergent care of suspected placenta previa and abruption (39). US resulted in a change in management in 33% of OB/GYN studies, with the greatest clinical impact in first trimester OB (86%). Van Dyk et al., in an open-cluster randomized trial investigating the effect of routine second trimester US on obstetric management and pregnancy outcomes in a South African community, found no significant differences between groups in terms of prenatal hospitalization, delivery, miscarriages, perinatal mortality and low birth weight rates (58). However, US screening was associated with a lower rate of induction of labor for post-term pregnancy.

Given poor access to antenatal care and screening in resource poor countries, Agunloye et al. conducted a study in Nigeria to evaluate the role of routine abdominal US scans in newborns, with the goal of detecting possible abnormalities which may have been missed antenatally (6). They found a 5.9% incidence of genitourinary abnormalities, primarily affecting the kidneys, suggesting that there is some benefit to routine pre- and post-natal screening. While Nigeria has

a high maternal and fetal mortality rate and could benefit significantly from routine US screening, investigators identified cost of equipment and lack of skilled personnel as major barriers to implementing this technology (6).

Abdominal Ultrasound

Several articles address the utility of abdominal ultrasound in evaluation and management of infectious diseases and malignancies. Dengue fever, a mosquito-borne viral disease, has an incidence of 390 million infections per year (62). Bharath Kumar Reddy et al. conducted a study in India using US to predict severity of dengue fever in children in India (16). Common findings in children with confirmed dengue were gallbladder wall thickening (75.9%), hepatomegaly (68.5%), pleural effusion (63.8%), and ascites (56.7%). In severe dengue fever, there was an increased finding of pericholecystic fluid collection (P=0.002), hepatic intraparenchymal fluid (P=0.001), splenic subcapsular fluid (P=0.002), peripancreatic fluid (P=0.002), perirenal fluid (P<0.001) and pericardial fluid (P = 0.002) compared to lower grades of disease.

Obajimi et al. conducted a study to describe the findings and evaluate clinical utility of abdominal US in HIV/AIDS patients in Nigeria (3). The HIV-positive group had a higher proportion of splenomegaly (13.5% vs 7.7%; p<0.01), lymphadenopathy (2% vs 1.3%; p<0.7), and renal abnormalities (8.4% vs 3.8%; p<0.02) compared to the HIV-negative group. There were no differences in hepatic and pancreatic abnormalities between groups.

With respect to malignancies, Marjerrison et al. conducted a study in Cameroon to evaluate the incidence of abdominal disease at diagnosis of Burkitt lymphoma as well as correlate the extent of disease at diagnosis with overall event-free survival (42). Abdominal involvement appeared to be as frequent as jaw disease at presentation (82% and 73%, respectively). The rate of abdominal disease detected by physical exam was significantly lower than the rate of disease detected using US (59% vs 83%, P = 0.0004). Event-free survival among patients whose disease was upgraded by US was better than that of patients with clinically diagnosed stage 3 disease (64% vs 33%).

Several studies also looked at US as a tool in the diagnosis and management of intussusception (IS) in children. Justice et al., in a study to evaluate the accuracy of US in the diagnosis of acute IS in infants in Vietnam, found a 97.5% sensitivity and 99% specificity (37). Krishnakumas et al. conducted a case series evaluating US-guided hydrostatic reduction in the management of IS, and found that 96% of intussusceptions were successfully reduced using US guidance (40). There was no recurrence after 24 hours and no reported complications.

Trauma US

Focused Assessment with Sonography for Trauma (FAST) is a rapid bedside US technique employed in trauma units to screen for hemopericardium and hemoperitoneum. A 2015 Cochrane review showed that FAST has a very high specificity but low sensitivity in detecting and excluding visceral injuries (63). In the developing world, where cost is a major factor and access to imaging is limited, FAST may be a useful and cost-effective tool in the evaluation and disposition of trauma patients. Smith et al. conducted a study in KwaZulu-Natal to evaluate to the utility of FAST in a developing world emergency department (54). FAST had a 100% specificity and sensitivity of 71.4% in the detection of intra-abdominal or pericardial free fluid. Crouch et al. conducted a study to evaluate confidence of Peruvian health workers in the FAST exam after an educational intervention (26). Participants were asked to complete a questionnaire based on a 5-point Likert scale (1=no confidence, 5=high confidence) to assess their comfort level with FAST before and after a two-day hands-on training workshop. Participants reported increased confidence in their FAST scan abilities (pre-training average score 3.3 (± 0.3) and post-training 4.5 (± 0.2); p=0.007) and comfort in using the exam for clinical decision-making (pre-training average score 3.5 (± 0.4) and post-training 4.5 (± 0.2); p=0.016).

Carotid Ultrasound

Given the high incidence of hypertension and stroke in developing countries, Agunloye et al. conducted a case control study in Nigeria to identify carotid sonographic parameters that may be associated with stroke risk among hypertensive patients (7). They found that the luminal diameter (>6.3 mm; adjusted odds ratio [OR], 8.91; 95% confidence interval [CI], 2.18–36.34; P = .002) and end-diastolic velocity (>21 cm/s; adjusted OR, 0.15; 95% CI, 0.03–0.71; P = .017) of the common carotid artery are significantly associated with stroke risk among hypertensive patients (7). There currently exist no formal sonographic diagnostic criteria or guidelines for comparison.

Thyroid Ultrasound

Amoah et al. conducted a study to determine the feasibility of using thyroid ultrasonography to estimate goiter prevalence in school children in Ghana (10). All children had a normal thyroid US. Thyroid volumes ranged from 3.6mL to 15.3mL. The criteria of thyroid volume per age and sex yielded a goiter prevalence of 1.8%. In contrast, the criteria of thyroid volume by surface area yielded a goiter prevalence of 8% (10).

Breast Ultrasonography

Breast health screening with mammography is often limited in the developing world. According to Galukande et al., the main challenges of mass screening include a lack of available mammography machines and trained human resources (28). They propose breast US as an alternative to mammography in Uganda and other resource-limited settings. The peak age for breast cancer in Uganda is 30-39 years, suggesting that screening should occur earlier than in developed nations where breast cancer peaks around age 50 (28). However, mammography is not efficacious in young women with dense breast tissue. Galukande et al. argue that while US is less sensitive and specific for radiographic breast screening, it may be a better alternative to no screening at all. In addition, US machines are 10-fold more available and

Table 1, Part I. Reviewed articles.

Author	Publication Year	Journal	Country	Specialty	Study Type
Adler, D	2008	Int. J. Emerg. Med.	Tanzania	Emergency medicine	Prospective observational
Agunloye, A	2011	BMC Pediatr.	Nigeria	Radiology and Pediatrics	Longitudinal
Agunloye, A	2014	J.Ultrasound Med.	Nigeria	Radiology and Medicine	Case-control
Akhtar, W	2011	J.Ultrasound Med.	Pakistan	Radiology	Observational
Akhtar, W	2010	J.Ultrasound Med.	Pakistan	Radiology	Opinion
Amoah, A	2004	Afr. J. Med. Sci.	Ghana	Internal medicine	Cross-sectional
Ansa, V	2013	Niger.J.Clin.Pract.	Nigeria	Cardiology	Cross-sectional
Cenydd, L	2009	Stud.Health Technol.Inform.	United Kingdom	Computer Science	Descriptive
Bartholomot, B	2002	Am. J. Trop. Med. Hyg.	China	Internal medicine	Cross-sectional
Bawa, M	2010	Indian Journal of Pediatrics	India	OBGYN	Case series
Beaton, A	2014	J.Am.Soc.Echocardiogr.	Uganda	Cardiology	Prospective observational
Bharath Kumar Reddy, K	2013	Pediatr.Radiol.	India	Radiology, Pediatrics	Prospective
Binkowski, A	2014	J.Emerg.Med.	USA	Emergency medicine	Prospective
Blaivas, M	2005	Wilderness Environ.Med.	Amazon Jungle	Emergency medicine	Prospective observational
Brindle, H	2013	Trans.R.Soc.Trop.Med.Hyg.	Malawi	Radiology	Prospective cross-sectional
Brown, D	2014	Ultrasound Q.	Not Reported	Radiology	Opinion
Bussman, H	2001	Tropical Medicine and International Health	Botswana	Radiology	Prospective observational
Chiavegatto Filho, A	2013	Int.J.Public.Health.	Brazil	Public Health	Retrospective cohort
Chigbu, C	2008	Int. J. Gynaecol. Obstet.	Nigeria	OBGYN	Descriptive
Colquhoun, S	2013	Cardiol.Young	Fiji	Public Health	Cross-sectional
Colquhoun, S	2014	Int.J.Cardiol.	Fiji	Public Health	Cross-sectional
Crouch, A	2010	Int. J. Emerg. Med.	Peru	Emergency medicine	Descriptive
Ferraioli, G	2007	AJR Am.J.Roentgenol.	Tanzania	Radiology, Infectious disease	Observational
Galukande, M	2010	Afr.Health.Sci.	Uganda	Radiology, Surgery	Opinion
Gammeltoft, T	2007	Soc.Sci.Med.	Vietnam	Anthropology	Observational
Geerts, L	2004	Int.J.Gynaecol.Obstet.	South Africa	OBGYN	Prospective controlled trial
Godown, J	2015	Pediatrics	Uganda	Cardiology	Observational
Greenwold, N	2014	Int.J.Gynaecol.Obstet.	Mozambique	Maternal and fetal medicine	Prospective cohort
Harris, R	2012	J.Ultrasound Med.	Not Reported	Radiology	Cross-sectional
Harvey, H	2014	AJR Am.J.Roentgenol.	Not Reported	Radiology, Emergency medicine	Opinion
Henwood, P	2014	Ann.Emerg.Med.	Not Reported	Emergency medicine	Report
Ismail, Y	2007	Trop.Doct.	Uganda	Cardiology	Observational
Justice, F	2007	Pediatr. Radiol.	Vietnam	Pediatrics	Prospective observational
Kobal, SL	2004	Am.J.Cardiol.	Mexico	Cardiology	Cross-sectional
Kotlyar, S	2008	J. Emerg. Trauma Shock	Liberia	Emergency medicine	Prospective observational
Krishnakumas, S	2006	Indian Journal of Pediatrics	India	Radiology	Case series
Levine, A	2010	Acad.Emerg.Med.	Rwanda	Emergency medicine	Prospective cohort
Mand, S	2011	Acta Tropica	Ghana	Internal medicine	Cross-sectional
Marjerrison, S	2012	Pediatr.Blood Cancer.	Cameroon	Pediatrics	Retrospective cohort
Maro, E	2004	Cent.Afr.J.Med.	Tanzania	Internal medicine	Descriptive
Marshburn, T	2004	J.Trauma	USA	Emergency medicine	Prospective observational
McClure, E	2014	BMC Pregnancy Childbirth	Pakistan, Kenya, Zambia, Congo, Guatemala	Epidemiology	Cluster randomized trial

Table 1, Part II. Reviewed articles.

Author	Publication Year	Journal	Country	Specialty	Study Type
Mirabel, M	2012	Eur.Heart J.Cardiovasc.Imaging	Mozambique	Cardiology	Retrospective observational
Murphy, S	2011	Pediatr. Crit. Care Med.	Uganda	Pediatrics	Prospective observational
Nathan, R	2014	Ultrasound Q.	Uganda	Radiology	Descriptive
Obajimi, M	2008	BMC Medical Imaging	Nigeria	Radiology	Prospective observational
Ome, M	2013	BMC Pediatr.	Papa New Guinea	Unknown	Case report
Pyke, J	2007	Conf.Proc.IEEE Eng.Med.Biol.Soc.	USA, Nicaragua	Radiology, Engineering	Descriptive
Rijken, M	2009	Ultrasound Obstet. Gynecol.	Thai-Burmese border	OBGYN	Case control
Rossi, E	2014	J.Heart Valve Dis.	Eritrea	Cardiology	Prospective observational
Shah, S	2009	BMC Int. Health and Human Rights	Rwanda	Emergency medicine	Longitudinal descriptive
Shah, S	2008	Int. J. Emerg. Med.	Rwanda	Emergency medicine	Descriptive
Smith, Z	2010	S. Afr. Med. J.	Kwazulu-Natal	Emergency medicine	Prospective observational
Spencer, J	2008	J. Ultrasound Med.	Ghana	Primary care	Prospective observational
Stolz, L	2015	Trop.Med.Int.Health	Uganda	Emergency medicine	Retrospective
Sutherland, J	2009	J.Telemed.Telecare	Dominican Republic	Internal medicine	Prospective observational
van Dyk, B	2007	Int. J. Gynaecol. Obstet.	South Africa	OBGYN	Open cluster randomized trial
Yacoub, S	2010	Crit.Care Med.	Kenya	Infectious Disease	Prospective observational

half the cost of mammography per exam, making it a much more viable option for developing countries. However, they do acknowledge that breast US is highly operator- and experience-dependent, which is likely a significant barrier to successful implementation as a screening tool in resource-poor settings.

Scrotal US

Mand et al. evaluated scrotal US as a tool to determine the frequencies of urogenital pathologies in men infected with Bancroftian filariasis, as well as differentiate between diverse pathologies with different clinical implications in Ghana (41). In 56% of patients, fluid accumulation around the testis was detected. Thirty-eight percent of these patients presented with subclinical stages of filariasis. Forty-seven percent of patients with fluid accumulation around the testis had echo-free hydrocele versus 9% with echo-dense hydrocele. Investigators showed that echo-free and echo-dense fluid could be differentiated and that a considerable number of cases had echo-dense hydrocele (9%), which poses a risk to develop necrotic testis and infertility, requiring immediate surgical intervention. Mand et al. concluded that US can be a useful diagnostic technique to differentiate between cases requiring immediate surgical intervention and those that can be treated medically (41).

Bone US

Marshburn et al. conducted a study to compare the accuracy of US versus physical exam for the identification of fractures of the humerus and femur (44). This study pertained to remote areas such as Antarctica, submarines, and naval surface vessels, where diagnostic imaging capabilities are limited or non-existent due to excessive size and weight. The sensitivity and specificity of US were 92.9% and 83.3%, and that of physical exam were 78.6% and 90%, respectively. Ultrasound was 100% sensitive in detecting humeral and femoral mid-shaft fractures. All inaccurate US interpretations occurred with femur fractures at or above the intertrochanteric line, most likely due to baseline surface irregularities of the greater trochanter and femoral neck. Marshburn et al. concluded that US scans may be a useful tool to rule out long-bone fracture in patients with medium to low probability of fracture (44).

Ocular US

Murphy et al. conducted a study in Uganda to establish a targeted US examination for children with malaria and to describe the prevalence of specific US findings in severe malaria syndromes (2). A focused US exam, including optic nerve sheath diameter, color transcranial doppler, cardiac US, and spleen size was performed on children with diagnosed Plasmodium falciparum malaria infection. Increased optic nerve sheath diameter was observed in one-third of patients with malaria and 100% of patients diagnosed with cerebral malaria. On cardiac US, no evidence of pulmonary hypertension or reduced cardiac function were encountered in these cases. Spleen size was frequently overestimated on palpation compared with US measurement.

Clinical Impact

In the twelve articles analyzed here, the clinical impact of US was evaluated as an imaging modality in the developing world (Table 2). Most of the research was conducted in the continent of Africa. Change in clinical management ranged from 7% to 62%, with most studies reporting greater than

Table 2. Clinical impact of ultrasound.

Author	Year	Location	Specialty	US modality	Clinical Impact
Blaivas, M.	2005	Amazon Jungle	Emergency Medicine	Variety	Change in management in 28% (7 patients)
Brindle, HE.	2013	Malawi	Radiology	Abdominal, Cardiac	Change in management in 57% of studies
Bussman, H.	2001	Botswana	Radiology	Variety	Improved case management in 30% (696 cases); Change in management in 7% (151 patients)
Godown, J.	2015	Uganda	Cardiology	Cardiac	Handheld US had 97.8% sensitivity and 87.3% specificity in detection of Rheumatic Heart Disease
Justice, FA.	2007	Vietnam	Pediatrics	Abdominal	97.6% sensitive and 99% specific in detection of Intussusception
Kotlyar, S.	2008	Liberia	Emergency Medicine	Variety	Change in management in 62% of cases
Levine, AC.	2010	Rwanda	Emergency Medicine	Aorta/IVC	Aorta/IVC ratio has 93% sensitivity and 59% specificity for identifying severe dehydration
Marjerrison, S.	2012	Cameroon	Pediatrics	Abdominal	Increased detection rate of abdominal disease compared to physical exam (83% vs 59%). Event free survival 64% among patients whose disease was upgraded by US
Marshburn, TH.	2004	USA	Emergency Medicine	Bone	92.9% sensitivity and 83.3% specificity in detection of longbone fractures
Shah, SP.	2009	Rwanda	Emergency Medicine	Variety	Change in management in 43% of patients
Smith, ZA.	2010	KwaZulu-Natal	Emergency Medicine	FAST	Overall 100% specificity and 71.4% sensitivity for detection of free fluid
Spencer, JK.	2008	Ghana	Primary care	Variety	81% of studies added to clinical diagnosis; 40% of studies led to change in management

40% change. In the majority of studies, US operators and providers commented on whether US altered their diagnosis or management plans. Kotlyar et al. and Blaivas et al. defined change in management when one of the following occurred: change in pre- versus post-US diagnoses by the referring physician, change in the disposition of patient after US, referral for surgical intervention because of ultrasound results, or addition/withdrawal of pharmacotherapy (18,39).

Ultrasound had a very high specificity across most studies confirming its role as a valuable diagnostic tool. In the majority of studies, US was performed by experienced operators (physicians, sonographers), and therefore may not reflect the true clinical impact if such technology were adopted by less experienced personnel. One study by Marshburn et al. addressed this issue by providing a one-hour training in bone US to inexperienced clinicians and found a high sensitivity and specificity in the detection of long-bone fractures (44). This suggests that US can be an effective tool even for inexperienced providers if given proper training, making it an ideal technology for the developing world where trained personnel are often lacking. While studies show that US can change clinical management, there are limited data on whether this translates to improved clinical outcomes in the developing world. Further research is needed to evaluate the clinical utility and outcomes of using US by non-physician providers, who would be the likely operators in resource-limited settings.

Barriers to Implementation

While US can be a valuable resource in the developing world, there are many barriers that must be considered prior to implementing this technology. Several studies cite cost as a major barrier, particularly the machine itself, maintenance, gel, Internet access for educational resources, expert advice and consultation, as well as expenses associated with training

personnel (6,9,11,12,17,20,27,34,36,55). Lack of formal US training programs appears to be another major barrier, with several studies reporting a significant need for experts to implement and teach such programs (6,9,12,20,27,43,54,55). As mentioned prior, if a remote web-based program is implemented, there are typically high costs associated with computer and Internet access for educational materials and consultation. In addition, language barriers may slow or hinder the learning process. Even if a US training program is successfully implemented, a lack of ongoing quality assurance via expert review and real-time feedback may lead to significant deficiencies in the quality of scans, resulting in overall poor sustainability of the program.

Consequences

While ultrasound is perceived as a safe imaging modality with extensive use in prenatal screening, there are theoretical risks that have been observed in the laboratory setting, particularly heat generation and cellular damage from the use of Doppler technology. As a result, many physicians will use caution early in pregnancy. Akhtar et al. conducted a survey to assess Pakistani end-user knowledge regarding safety aspects of diagnostic US during pregnancy (9). Approximately 75% of participants reported no adverse effects to the fetus during an US exam. 8.7% of participants reported routinely performing Doppler scans during the first trimester of pregnancy. About half of participants reported that there should be limitations to the use of ultrasound during low-risk pregnancy. Operators who were concerned about limitations on the use of ultrasound during pregnancy were 2.5 and 1.8 times more likely to be familiar with the mechanical and thermal indices, respectively, which are on-screen indicators that show the potential of ultrasound-induced bioeffects (9).

As described by Ome et al., increased use of obstetric US will likely lead to an increase in prenatal detection of congenital abnormalities (48). This can have significant implications for resource-limited settings, where cultural beliefs and attitudes surrounding birth defects may result in increased rates of abortions (22,29,32). Even if parents opt to proceed with the pregnancy, one must also consider the lack of healthcare infrastructure for referral and management of such complex pathology. Given the potential implications of prenatal US in resource-limited settings, parents must be counseled on its use and limitations. In particular, parents must have an understanding that US is operator-dependent and relies on one's level of training.

Several articles expressed concerns that introduction of US technology in regions of low income and high poverty may result in sex-selective abortions (22,32). This was explored by Chiavegatto et al. who evaluated the presence of sex-selective abortions with the introduction of US equipment in a very poor area of Brazil (22). They found a sex ratio of 1.039 for municipalities that had introduction of US equipment, and 1.047 for those that did not, which was not statistically significant (22). Based on these results, authors concluded that while sex-selective abortions are an important concern, it should not be a barrier against access to maternal technology.

Conclusion

Ultrasound has widespread clinical applications, particularly as a diagnostic tool in the developing world. While several studies report a significant clinical impact with the use of US technology, there remain considerable barriers with respect to access and training in resource-limited settings. The adoption of ultrasound technology may also have social and cultural ramifications that need to be considered. Further research is needed to better understand the impact of various US modalities on diagnosis, management and patient outcomes in different resource-limited settings.

Conflict of interest

The authors report no conflict of interest.

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