SYSTEMATIC REVIEW

Trends in Ultrasound Use in Low and Middle Income Countries: A Systematic Review

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ABSTRACT

Background: Evidence on recent trends regarding the impact and cost-benefits of ultrasound in resource-constrained settings is limited. This study presents a systematic review to determine recent trends in the utility and applicability of ultrasound use in low and middle income countries (LMIC). The review includes characterizing and evaluating trends in (1) the geographic and specialty specific use of ultrasound in LMICs, (2) the innovative applications and the accompanying research findings, and (3) the development of associated educational and training programs.

Methods: The electronic databases Medline OVID, EMBASE, and Cochrane were searched from 2010 to 2018 for studies available in English, French, and Spanish. Commentaries, opinion articles, reviews and book chapters were excluded. Two categories were created, one for reported applications of ultrasound use in LMICs and another for novel ultrasound studies.

Results: A total of 6,276 articles were identified and screened, 4,563 studies were included for final review. 287 studies contained original or novel applications of ultrasound use in LMICs. Nearly 70% of studies involved ultrasound usage originating from Southeast Asia and sub-Saharan Africa, the latter being the region with the highest number of innovative ultrasound use. Educational studies, global collaborations, and funded studies were a substantial subset of overall ultrasound research. Our findings are limited by the lack of higher quality evidence and limited number of randomized clinical trials reported.

Conclusion/Global Health Implications: Our systematic literature review of ultrasound use in LMICs demonstrates the growing utilization of this relatively low-cost, portable imaging technology in low resource settings.

Key words: • Ultrasound • Ultrasonography • Echocardiogram • LMIC • Low resource • Global health • Systematic review
1. Introduction

Ultrasonography is a clinically accepted imaging modality that enables a low-powered, mobile diagnostic pathway that can be readily learned by a variety of medical personnel to enable rapid assessment and treatment in a variety of settings. Ultrasonography devices are able to be used by a single-operator, handheld, and can provide diagnostic capabilities at a much lower cost than other imaging tools such as Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). These characteristics make ultrasonography (otherwise referred to as ultrasound (US)) an attractive option for clinical use in low and middle income countries (LMICs) for both in-patient and out-patient use.

In 1997, the World Health Organization (WHO) estimated that 50% of the developing world did not have access to ultrasound imaging, and where it was available, equipment was outdated or broken. Technically trained maintenance for machine repair and the circulation of unregulated ultrasound equipment presented barriers to imaging access in metropolitan areas, in addition to the substantial lack of access to healthcare and imaging resources in rural areas. However, recognition of the potential advantages of ultrasound imaging in low resource settings has spurred the growth of ultrasound machine availability, diagnostic capability, trained technologists, educational and training programs, research and overall ultrasound utilization in LMICs.

Despite this progress, there has been little recent literature on the applications of ultrasound in LMICs, including new uses for diagnosis and treatment adapted for medical challenges in low resource settings. We conducted a systematic review to determine recent trends in the utility and applicability of ultrasound use in LMICs.

2. Methods

We performed a systematic review of the literature with search strategy development assistance by a trained medical librarian (LO) at Baylor College of Medicine. Medline OVID, EMBASE, and Cochrane Clinical Trials were searched with the developed strategy for English, Spanish and French articles from 2010 to 2018. Low and middle income countries were selected by the World Bank definition and categorization in the year 2018; countries with low income economies and lower-middle economies were chosen for inclusion. Commentaries, opinion articles, reviews and book chapters were excluded. The last search was completed on April 4th, 2019.

Two categories for study selection were created; (1) ‘applications of ultrasound,’ or all studies using ultrasound imaging technology in a medical context, and a sub-category, (2) ‘novel ultrasound research.’ Novel ultrasound research studies were selected from articles included in the first category, and were defined as involving novel application of ultrasound technology in a low resource setting, involving the use of a hand-held ultrasound probe, or including educational and training curriculum on ultrasound imaging in a low resource setting. For example, “Simplified rheumatic heart disease screening criteria for handheld echocardiography” was included as a novel study, but “Prevalence of rheumatic heart disease in Zambian school children” was not included as a novel study. Both were included in the systematic review of all ultrasound studies in LMICs.

Study selection was performed independently by three researchers (SN, GT and SK), discrepancies between reviewers were resolved by KS. Data extraction was performed using a standardized template by five researchers (SN, SL, GT, SK and RP) and reviewed by KS.

Data collected on all ultrasound studies include the year of publication, journal title, article title, country, and geographical region. Data collected on novel ultrasound studies include (in addition to the above) the hospital type (public vs. private), institution type (tertiary, district or primary care health center), study design, name of first and last author, institution of first and last author, and country of first and last
Ultrasound Use in Low and Middle Income Countries

author, application of ultrasound, medical specialty, type of ultrasound machine, skill level of provider, title of provider, descriptive findings of the study, and study outcomes (depending on study design). Novel ultrasound research articles that were randomized controlled trials were reviewed and graded according to the Cochrane Risk of Bias Tool. Data was aggregated and analyzed in Excel (Microsoft, Redmond, WA, USA). Statistical analysis was performed in SPSS (V.21, IBM, Armonk, NY, USA).

This study was exempt from institutional review board approval. The review protocol has not been previously published or registered. We completed our review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

3. Results

Initial database search (after deduplication) yielded 6,276 articles (Figure 1). Abstracts were reviewed for inclusion, after which 1,713 studies were excluded for not reporting ultrasound use, describing non-clinical applications, or for studies not performed in an LMIC. An additional 287 articles were included in the novel research sub-category as defined above. Nine articles that met novel research

Figure 1: PRISMA flow diagram

Novel: designates novel ultrasound research studies (n=287); Application: designates all applications of ultrasound studies included in review (n=3,888)

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criteria were excluded after the full-text was not available for review, with an additional 5 articles excluded for being research studies conducted in a military setting.

Trends by year and geographical region of ultrasound use in LMICs for all studies and novel ultrasound studies are shown in Figures 2 and 3. The number of countries with reported ultrasound use has increased 24% since 2010 from 50 to 62 countries. The countries with the highest number of ultrasound studies included India (20%), Egypt (9.8%), Nigeria (8.8%), and Pakistan (7.3%). The specialties represented in all ultrasound studies included cardiology (25%), obstetrics and gynecology (14%). Other key specialties included gastroenterology (7.3%), pediatrics (5.8%), infectious disease (5.7%), internal medicine (6.2%), endocrinology (2.9%), and general surgery (3.5%). The most common journals of publication were the Indian Heart Journal (n=103), the Pan African Medical Journal (n=77), the Journal of Medical Case Reports (n=57), Mymensingh Medical Journal (n=53), Pakistan Journal of Medical Sciences (n=50), PLoS ONE (n=48), and BMC Research (n=44).

Figure 2: Ultrasound studies in LMIC over time
Novel: designates novel ultrasound research studies; Application: designates all applications of ultrasound studies included in review

Figure 3: Ultrasound studies in LMIC by geographical region
Novel: designates novel usage of ultrasound studies; Application: designates all non-novel application of ultrasound studies included in review
Of the 287 novel ultrasound application studies, 48% were prospective studies, 13% qualitative, 12% retrospective, 11% cross-sectional studies, 8% case reports, 5% randomized controlled trials, and 1.0% case-controls. Studies were largely performed at public hospitals (86%), of which 59% were conducted at tertiary hospitals and 41% were carried out in a primary care or rural setting. Novel research studies in the form of RCTs are shown in Table 1.

The novel applications of ultrasound technology in novel studies was primarily for screening (26%) and obstetrical use (34%), however, key applications also included infectious disease (10%), cardiology (9%), abdominal conditions (8%), trauma (8%), and gynecologic conditions (3%). Ultrasound imaging providers in novel studies included physicians (85%), midwives (7%), residents (3%), community health workers (2%), and ultrasound technicians (2%). Hand-held ultrasound devices were used in 28% (n=47) of novel studies. The most common journals of publication for novel ultrasound research include the Journal of Ultrasound in Medicine (n=12), BMC Pregnancy and Childbirth (n=7), Critical Ultrasound Research (n=7), PLoS ONE (n=6), Egyptian Journal of Radiology and Nuclear Medicine (n=5), the Egyptian Journal of Chest Diseases and Tuberculosis (n=5), and the American Journal of Tropical Medicine and Hygiene (n=5).

Global collaboration, defined as the inclusion of at least one author whose listed publication affiliation was within the country in which the novel ultrasound study was conducted, was present in 70% of studies. The majority of studies that involved global collaboration occurred in India (n=22), Uganda (n=22), Nigeria (n=15) and Tanzania (n=15). Of first authors, 67% were from the country of ultrasound study, of last authors, 60% were from the country of ultrasound study. A total of 75 papers (26%) included both a first and last author from the country of ultrasound study, including 18 from India and 14 from Nigeria. Thirty one percent of novel ultrasound research was funded (n=91), including by NIH grants, the Bill and Melinda Gates Foundation, the General Electric (GE) Foundation, and European foundation grant funding. The countries with the most number of studies with funding were Uganda (n=13), Tanzania (n=10), and Rwanda (n=6). Using the Cochrane risk of bias tool, 70% of the studies reviewed were characterized of having more than one categorized medium and high risk of bias for at least one ‘Risk of Bias’ category.

Sixty eight percent of novel research studies (n=196) contained an educational or training component on ultrasound imaging. Of those educational studies, 91 (46.4%) occurred in the sub-Saharan geographical region, including a majority in Uganda (n=20), Nigeria (17), and Tanzania (n=9). Details of educational studies with funding and known ultrasound, including a description of the training program or curriculum, are shown in Table 2. The number of annual educational ultrasound studies has increased to nearly 2.9 times the amount from 2010 to 2018 (from 14 to 40 per year).

4. Discussion

Increasing Use of Ultrasound

Our systematic literature review of ultrasound use in LMICs demonstrates the growing utilization of this relatively low-cost, portable imaging technology in low resource settings. Although the WHO does not measure access to ultrasound alongside other imaging modalities such as CT and MRI, it does recognize the importance of ultrasound imaging and its potential impact on diagnostics worldwide.4 This includes a goal of meeting 90% of imaging needs in primary health care settings with the use of a general purpose ultrasound machine combined with an X-ray unit, along with distribution of the WHO published Manual of Diagnostic Ultrasound.5 Our study demonstrates that research studies regarding ultrasound use in LMICs have increased nearly 60% and expanded 20% geographically in the last ten years in efforts to meet those goals. However, evidence also suggests that the majority of ultrasound studies were conducted at tertiary care centers (more than 70% of all ultrasound studies) and within middle-income countries, demonstrating broader problems with lack of access to healthcare in low-income economies and especially in rural areas.

Regional Trends of Ultrasound

Examining the regional breakdown of ultrasound related studies in LMICs, our study determined
<table>
<thead>
<tr>
<th>First Author</th>
<th>Year</th>
<th>Title</th>
<th>Journal</th>
<th>Country</th>
<th>N</th>
<th>Outcome measured</th>
<th>Outcome Field</th>
<th>Ultrasound used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akudu</td>
<td>2018</td>
<td>Ultrasonographic study of the incidence of pyramidal lobe and agenesis of the thyroid isthmus in Nnewi population</td>
<td>Journal of Ultrasonography</td>
<td>Nigeria</td>
<td>321</td>
<td>Rate of abnormal thyroids screened</td>
<td>Internal Medicine</td>
<td>Siemens Sonoline Prima</td>
</tr>
<tr>
<td>Ansa</td>
<td>2013</td>
<td>The clinical utility of echocardiography as a cardiological diagnostic tool in poor resource settings</td>
<td>Nigerian Journal of Clinical Practice</td>
<td>Nigeria</td>
<td>244</td>
<td>Percent of echocardiography confirmation of suspected heart abnormalities</td>
<td>Cardiology</td>
<td>ALOKA SSD 4000</td>
</tr>
<tr>
<td>Beaton</td>
<td>2015</td>
<td>The utility of handheld echocardiography for early rheumatic heart disease diagnosis: a field study</td>
<td>Eur Heart J Cardiovasc Imaging</td>
<td>Uganda</td>
<td>4773</td>
<td>HAND Echo relative sensitivity / specificity for RHD detection</td>
<td>Cardiology</td>
<td>GEVivid-I; GEVscan</td>
</tr>
<tr>
<td>Beaton</td>
<td>2014</td>
<td>The utility of handheld echocardiography for early diagnosis of rheumatic heart disease</td>
<td>J Am Soc Echocardiogr</td>
<td>Uganda</td>
<td>125</td>
<td>HAND Echo ability to distinguish normal patients vs those with RHD sensitivity and specificity</td>
<td>Cardiology</td>
<td>GEVivid-I; GEVscan</td>
</tr>
<tr>
<td>First Author</td>
<td>Year</td>
<td>Title</td>
<td>Journal</td>
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<tr>
<td>Bhavnani27</td>
<td>2018</td>
<td>A Randomized Trial of Pocket Echo Integrated Mobile Health Device Assessments in Modern Structural Heart Disease Clinics</td>
<td>JACC Cardiovascular Imaging</td>
<td>India</td>
<td>253</td>
<td>Percentage reduction in risk of hospitalization and/or death</td>
<td>Internal Medicine</td>
<td>GEVScan</td>
</tr>
<tr>
<td>Cherniak28</td>
<td>2017</td>
<td>Effectiveness of advertising availability of prenatal ultrasound on uptake of antenatal care in rural Uganda: A cluster randomized trial</td>
<td>PLoS ONE</td>
<td>Uganda</td>
<td>157</td>
<td>The number of women receiving antenatal treatment in advertised arm vs non-advertised arm</td>
<td>Obstetrics &amp; Gynecology</td>
<td>Portable - not specified</td>
</tr>
<tr>
<td>Choi9</td>
<td>2011</td>
<td>Interpretation of remotely downloaded pocket-size cardiac ultrasound images on a web-enabled smartphone: Validation against workstation evaluation.</td>
<td>Journal of the American Society of Echocardiography</td>
<td>Honduras</td>
<td>89</td>
<td>Intraobserver agreement comparing interpretations on workstations and smartphones</td>
<td>Cardiology</td>
<td>GEVscan</td>
</tr>
<tr>
<td>Greenwold11</td>
<td>2014</td>
<td>Implementing an obstetric ultrasound training program in rural Africa</td>
<td>Int J Gynaecol Obstet</td>
<td>Mozambique</td>
<td>1734</td>
<td>Percentage of scans with a clinical impact</td>
<td>Obstetrics &amp; Gynecology</td>
<td>M-Turbo (Sonosite, Bothell, WA, USA) portable ultrasound</td>
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<tr>
<td>First Author</td>
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<tr>
<td>McClure</td>
<td>2014</td>
<td>First look: a cluster-randomized trial of ultrasound to improve pregnancy outcomes in low income country settings</td>
<td>BMC Pregnancy &amp; Childbirth</td>
<td>Multiple</td>
<td>TBD</td>
<td>TBD - underway</td>
<td>TBD</td>
<td>Obstetrics &amp; Gynecology</td>
</tr>
<tr>
<td>Nathan</td>
<td>2014</td>
<td>Screening obstetric ultrasound training for a 5-country cluster randomized controlled trial</td>
<td>Ultrasound Quarterly</td>
<td>Multiple</td>
<td>29</td>
<td>TBD - underway</td>
<td>TBD</td>
<td>Obstetrics &amp; Gynecology</td>
</tr>
<tr>
<td>Ome-Kaius</td>
<td>2017</td>
<td>Effects of Plasmodium falciparum infection on umbilical artery resistance and intrafetal blood flow distribution: a Doppler ultrasound study from Papua New Guinea</td>
<td>Malaria Journal</td>
<td>Papua New Guinea</td>
<td>78</td>
<td>Adjusted odds ratio of doppler measurement associated with increased umbilical artery resistance</td>
<td>2.3 (95% CI 1.0–5.2)</td>
<td>Obstetrics &amp; Gynecology</td>
</tr>
<tr>
<td>Robertson</td>
<td>2011</td>
<td>Pilot randomized trial of therapeutic hypothermia with serial cranial ultrasound and 18-22 month follow-up for neonatal encephalopathy in a low resource hospital setting in Uganda: study protocol</td>
<td>Trials</td>
<td>Uganda</td>
<td>40</td>
<td>Risk ratio and absolute difference of mortality in cooled compared to standard care group</td>
<td>5.0 (95% CI 0.7-37, 0.267 (95% CI 0.029, 0.505)</td>
<td>Pediatrics</td>
</tr>
</tbody>
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HAND: Handheld echocardiography, RHD: Rheumatic heart disease, CI: Confidence interval
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<th>Funding</th>
<th>N</th>
<th>Outcome measure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boamah&lt;sup&gt;36&lt;/sup&gt;</td>
<td>2014</td>
<td>Gestational Age Assessment in the Ghana Randomized Air Pollution and Health Study (GRAPHS): Ultrasound Capacity Building, Fetal Biometry Protocol Development, and Ongoing Quality Control</td>
<td>JMRIR Research Protocols</td>
<td>Ghana</td>
<td>Obstetrics and Gynecology</td>
<td>S180 (Sonosite Inc, Bothell, WA USA)</td>
<td>Use of ultrasound should be considered in field-based trials involving pregnant women to predict GA</td>
<td>NIH</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Colquhoun&lt;sup&gt;16&lt;/sup&gt;</td>
<td>2013</td>
<td>Pilot study of nurse-led rheumatic heart disease echocardiography screening in Fiji—a novel approach in a resource-poor setting</td>
<td>Cardiology in the Young</td>
<td>Fiji</td>
<td>Cardiology</td>
<td>Model 5 (Mindray, Shenzhen, CN)</td>
<td>Nurses with brief focused training and supervised field experience can follow an algorithm to perform echocardiogram identifying rheumatic heart disease</td>
<td>Cure Kids New Zealand</td>
<td>50</td>
<td>Specificity, sensitivity</td>
<td>100% Nurse A, 83% Nurse B; 67.4% Nurse A, 79% Nurse B</td>
</tr>
<tr>
<td>Epstein&lt;sup&gt;37&lt;/sup&gt;</td>
<td>2018</td>
<td>Pocket-size point-of-care ultrasound in rural Uganda - A unique opportunity “to see”, where no imaging facilities are available</td>
<td>Travel Medicine &amp; Infectious Disease</td>
<td>Uganda</td>
<td>Radiology</td>
<td>Vscan GE (General Electric, Milwaukee,WI, USA)</td>
<td>POCUS resulted in change of management</td>
<td>Eldan-Life Sciences</td>
<td>23</td>
<td>Percent of cases in which US image prompted change of clinical management occurred</td>
<td>87.0%</td>
</tr>
<tr>
<td>Kimberly&lt;sup&gt;38&lt;/sup&gt;</td>
<td>2010</td>
<td>Focused maternal ultrasound by midwives in rural Zambia</td>
<td>Ultrasound in Medicine &amp; Biology</td>
<td>Zambia</td>
<td>Obstetrics &amp; Gynecology</td>
<td>S180 (Sonosite Inc, Bothell, WA USA)</td>
<td>Midwives in rural Zambia can be trained to perform basic obstetric ultrasound to improve clinical decision-making</td>
<td>US machines provided by SonoSite</td>
<td>441</td>
<td>Percent of cases in which US image prompted change in clinical decision making</td>
<td>17%</td>
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<td>First Author</td>
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<tr>
<td>Kirkpatrick</td>
<td>2018</td>
<td>Focused Cardiac Ultrasound by Nurses in Rural Vietnam</td>
<td>Journal of the American Society of Echocardiography</td>
<td>Vietnam</td>
<td>Cardiology</td>
<td>Model 7 (Mindray, Shenzen, CN)</td>
<td>Nurses with no prior echocardiographic experience and with limited training can identify patients with significant cardiac abnormalities using FCU with acceptable accuracy</td>
<td>Society of Echocardiography Foundation</td>
<td>8</td>
<td>Specificity, sensitivity, and accuracy of echocardiograms read by nurses</td>
<td>51.5%, 78.1%, 61.9%</td>
</tr>
<tr>
<td>Kozuki</td>
<td>2016</td>
<td>Accuracy of Home-Based Ultrasonographic Diagnosis of Obstetric Risk Factors by Primary-Level Health Care Workers in Rural Nepal</td>
<td>Obstetrics &amp; Gynecology</td>
<td>Nepal</td>
<td>Obstetrics &amp; Gynecology</td>
<td>Nanomaxx (Sonosite Inc, Bothell, WA USA)</td>
<td>With limited training, primary-level health care workers in rural Nepal can accurately diagnose selected third trimester obstetric risk factors using ultrasonography</td>
<td>Children's Prize, National Institutes of Health / Bill and Melinda Gates Foundation / SonoSite</td>
<td>815</td>
<td>Sensitivity, specificity, positive and negative predictive values for 3 auxiliary nurse midwives</td>
<td>90 to 100% for all outcomes of all 3 midwives</td>
</tr>
<tr>
<td>Kwan</td>
<td>2013</td>
<td>A simplified echocardiographic strategy for heart failure diagnosis and management within an integrated noncommunicable disease clinic at district hospital level for sub-Saharan Africa</td>
<td>JACC Heart Failure</td>
<td>Rwanda</td>
<td>Cardiology</td>
<td>MicroMaxx (Sonosite Inc, Bothell, WA USA)</td>
<td>Training nurses, supervised by physicians, in simplified protocols and basic echocardiography is one approach to integrated, decentralized care for this vulnerable population</td>
<td>National Scientist Development Award (AHA)</td>
<td>192</td>
<td>Observed mortality with long-term nurse follow-up (comparable to non-nurse follow up data)</td>
<td>0.09</td>
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<thead>
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<th>First Author</th>
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<th>Outcome measure</th>
<th>Outcome measure</th>
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</thead>
<tbody>
<tr>
<td>Leopold⁴</td>
<td>2018</td>
<td>Point-of-care lung ultrasound for the detection of pulmonary</td>
<td>PLoS ONE</td>
<td>Bangladesh</td>
<td>Pulmonology</td>
<td>GE Healthcare Vivid-I Portable (General Electric,</td>
<td>LUS was highly feasible and allowed accurate identification of patients at risk of death in a resource limited setting</td>
<td>Wellcome Trust</td>
<td>102</td>
<td>Percentage of patients who</td>
<td>86%</td>
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<td></td>
<td></td>
<td>manifestations of malaria and sepsis: An observational study</td>
<td></td>
<td></td>
<td></td>
<td>Milwaukee, WI, USA)</td>
<td>ätze</td>
<td></td>
<td></td>
<td>died with lung US abnormalities</td>
<td></td>
</tr>
<tr>
<td>Lu⁴</td>
<td>2015</td>
<td>Simplified rheumatic heart disease screening criteria for handheld</td>
<td>Journal of the American Society</td>
<td>Uganda</td>
<td>Cardiology</td>
<td>GE Vivid q or i or Philips CX-50 (General Electric,</td>
<td>In resource-limited settings, HAND with simplified criteria can detect rheumatic heart disease with good sensitivity and specificity and decrease the need for standard echocardiography</td>
<td>NIH National Center for Advancing Translational Sciences</td>
<td>1439</td>
<td>Mitral regurgitation detection sensitivity and specificity</td>
<td>73.3%, 82.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>echocardiography</td>
<td>of Echocardiography</td>
<td></td>
<td></td>
<td>Milwaukee, WI, USA)</td>
<td>ätze</td>
<td></td>
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<tr>
<td>Madimenos⁴</td>
<td>2011</td>
<td>Normative calcaneal quantitative ultrasound data for the indigenous</td>
<td>Archives of Osteoporosis</td>
<td>Ecuador</td>
<td>Orthopedics</td>
<td>Sahara bone sonometer (Hologic, Inc., Waltham, MA).</td>
<td>In both populations and sexes, all calcaneal QUS values were progressively decreased with advancing age. These normative data for calcaneal QUS parameters will be useful for predicting fracture risk and determining diagnostic criteria of osteoporosis in these populations</td>
<td>Wenner-Gren Foundation; NSF; Evonuk Foundation; Leakey Foundation; Ryoichi Sasakawa Young Leaders Fellowship; NIH</td>
<td>488</td>
<td>Difference in calcaneal QUS values between Shuar and Colonos</td>
<td>P &lt; 0.001</td>
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<td>First Author</td>
<td>Year</td>
<td>Title</td>
<td>Journal</td>
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<td>Funding</td>
<td>N</td>
<td>Outcome measure</td>
<td>Outcome</td>
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<td>Mand[^6]</td>
<td>2011</td>
<td>The role of ultrasonography in the differentiation of the various types of filaricele due to bancroftian filariasis.</td>
<td>Acta Tropica</td>
<td>Ghana</td>
<td>Urology</td>
<td>S180 Plus (Sonosite Inc, Bothell, WA USA)</td>
<td>In an unexpected high number of men, fluid accumulation around the testis was detected by US, of which more than one third presented with subclinical stages.</td>
<td>Bill and Melinda Gates Foundation</td>
<td>1453</td>
<td>Patients without hydrocele and subclinical disease had thinner scrotal skin than those in clinical stages with lymphscrotum</td>
<td>P &lt; 0.001</td>
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<tr>
<td>Michels[^6]</td>
<td>2013</td>
<td>The predictive diagnostic value of serial daily bedside ultrasonography for severe dengue in Indonesian adults.</td>
<td>PLoS Neglected Tropical Diseases</td>
<td>Indonesia</td>
<td>Infectious Disease</td>
<td>Signos personal ultrasound</td>
<td>Serial ultrasonography in contrast to existing markers such as hematocrit, may better identify patients at risk for development of severe dengue</td>
<td>Radboud University Nijmegen Medical Center</td>
<td>77</td>
<td>Positive predictive value and negative predictive value for severe dengue of subclinical plasma leakage seen on US</td>
<td>35%, 90%</td>
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<td>Mirabel[^7]</td>
<td>2015</td>
<td>Screening for rheumatic heart disease: evaluation of a focused cardiac ultrasound approach.</td>
<td>Circulation. Cardiovascular Imaging</td>
<td>New Caledonia</td>
<td>Cardiology</td>
<td>V-scan (General Electric, Milwaukee, WI, USA)</td>
<td>FCU by nonexperts using pocket devices seems feasible and yields acceptable sensitivity and specificity for rheumatic heart disease detection when compared with the state-of-the-art approach</td>
<td>French Federation of Cardiology</td>
<td>1217</td>
<td>Sensitivity and specificity of FCU to detect rheumatic heart disease by two nurses</td>
<td>83.7%, Nurse A, 77.6%, Nurse B; 90.9% Nurse A, 92.0% Nurse B</td>
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<tr>
<td>First Author</td>
<td>Year</td>
<td>Title</td>
<td>Journal</td>
<td>Country</td>
<td>Field</td>
<td>Ultrasound used</td>
<td>Findings</td>
<td>Funding</td>
<td>N</td>
<td>Outcome measure</td>
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<td>Murphy</td>
<td>2011</td>
<td>Ultrasound findings in Plasmodium falciparum malaria: a pilot study</td>
<td>Pediatric Critical Care Medicine</td>
<td>Uganda</td>
<td>Pediatrics</td>
<td>Micromaxx (Sonosite Inc, Bothell, WA USA)</td>
<td>A targeted ultrasound examination focusing on optic nerve sheath diameter, color transcranial Doppler, cardiac ultrasound, and spleen size may prove useful for patient classification, risk stratification, research studies, and treatment monitoring in pediatric malaria</td>
<td>Department of Pediatrics, Massachusetts General Hospital for Children.</td>
<td>33</td>
<td>Increased optic nerve sheath diameter in patients with malaria, and in patients with cerebral malaria</td>
<td>33%, 100%</td>
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<td>Ploutz</td>
<td>2016</td>
<td>Handheld echocardiographic screening for rheumatic heart disease by non-experts</td>
<td>Heart</td>
<td>Uganda</td>
<td>Cardiology</td>
<td>GEVscan V.1.2 (GE Medical Systems, Milwaukee, WI, USA)</td>
<td>Non-expert-led HAND screening programmes offer a potential solution to financial and workforce barriers that limit widespread rheumatic heart disease screening</td>
<td>NIH and National Center for Advancing Translational Sciences; General Electric Foundation</td>
<td>1002</td>
<td>Simplified approaches sensitivity and specificity to diagnose rheumatic heart disease</td>
<td>74.4%</td>
</tr>
<tr>
<td>Reynolds</td>
<td>2016</td>
<td>Bedside ultrasound training at Muhimbili National Hospital in Dar es Salaam, Tanzania and Hospital San Carlos in Chiapas, Mexico</td>
<td>African Journal Of Emergency Medicine</td>
<td>Tanzania</td>
<td>Internal Medicine</td>
<td>DP3300 (Mindray, Shenzhen, CN)</td>
<td>Introducing bedside ultrasound training in two distinct resource-limited settings was feasible and well-received</td>
<td>Abbott Fund, UCSF Global Health Sciences; Sonosite</td>
<td>22</td>
<td>Pass rate of final exam at both sites</td>
<td>100%</td>
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</tbody>
</table>

*All novel ultrasound studies with prospective design, funding source and model of ultrasound used. GA: Gestational age, NIH: National Institutes of Health, NA: Not applicable, POCUS: Pocket-sized point-of-care ultrasound, FCU: Focused cardiac ultrasound, LUS: Lung ultrasound, HAND: Handheld echocardiography, QUS: Quantitative ultrasound*
that nearly 70% of studies involved ultrasound usage originating from Southeast Asia and sub-Saharan Africa. In terms of novel ultrasound research conducted in LMICs, the region with the most studies was Western and sub-Saharan Africa (46.7%), driven by research conducted in Nigeria, Uganda, and Tanzania. 72% of studies involved global collaboration, meaning an author from an LMIC was present in the final publication. This lack of representation of authors from LMICs indicates that global collaboration could and should be increased, with the goal of 100% of research efforts and the subsequent academic publications involving collaboration with LMIC partners in the country where the research was conducted. This represents a potential lack of representation seen in other areas of publication.

**Focus of Studies**

The majority of ultrasound studies focused on cardiology, which described usage of portable echocardiograms, and obstetrics where the use of ultrasound in prenatal care is standardized. Pediatric care, gastroenterology, and internal medicine were specialties that conducted substantial research with ultrasound in the LMICs. Looking at novel applications of ultrasound, we found the increasing application of US as a screening tool was utilized, with novel applications including screening for Crimean-Congo hemorrhagic fever in Turkey, human cystic echinococcosis in Morocco, and dengue fever severity in India. Other noteworthy applications of novel ultrasound research included the deployment of a wind-up powered fetal heart monitor in Uganda conducted by Byaruhanga et al and the development of a machine learning model to classify chronic liver disease severity based on liver ultrasound in India by Bharti et al.

**Types of Studies**

Many studies on the use of ultrasound in LMICs were qualitative studies understanding the perceptions of ultrasound use, most commonly examining community perceptions of routine ultrasound imaging during pregnancy. Of note, perceptions about routine prenatal ultrasound care among physicians, midwives, and patients were studied. For example, the use of ultrasound in standard prenatal care was measured in several countries, as it represented a new phenomenon and was found to be essential to improving maternal outcomes. Key studies conducted in Tanzania, Uganda, Nigeria, Ghana evaluated the changing perception of obstetric ultrasound use for prenatal care. We found that ‘novel ultrasound research’ was published more often in international journals than ‘applications of ultrasound’ studies, which were commonly published in regional journals, i.e. PLoS ONE versus the Indian Heart Journal.

**Educational Programs**

We found that the rate of educational studies remained relatively consistent over the period studied. However, many of the educational studies focused on task-shifting from skilled providers to training for lay providers including midwives, medical students, community health workers, or other lay people. This includes the emerging role of teleconsultation services and tele-imaging in ultrasound around the world. For example, Bansal et al conducted the VISION-in-Tele-Echo study which evaluated the benefit of a teleremote training program in echocardiography in India, and Colquhoun et al conducted a pilot study of nurse-led rheumatic heart disease echocardiography screening in Fiji. Furthermore, some studies combined educational training programs alongside a measurable impact on increased screening and diagnosis. The study conducted by Chamadol et al outlined the teleconsultation program launched in Thailand for the diagnosis of cholangiocarcinoma, while simultaneously capturing the additional patients screened and health centers impacted by the program. Finally, the availability of ultrasound gel was identified as a potential barrier to use due to cost and lack of availability of commercially produced ultrasound gel. Several studies outlined low cost recipes for generic ultrasound gel, including the use of shampoo, Guar Gum, corn starch, lotion, and Betadine.

**Overall Trends**

Our study identified the overall trend of increasing studies in ultrasound application in LMICs over
the past decade. There has been increased use of ultrasound with new applications of technology simultaneously focused on the increased application in rural health care centers. Furthermore, research in ultrasound studies indicates a trend of increased training programs, using teleremote technologies to expand task shifting to lay providers, and ingenuity in using this low-cost technology in new ways adapted for low-resource settings. The findings outlined in the literature indicated the increased scope of ultrasound and its use in LMICs, where such a low cost, portable, diagnostic imaging modality is an extremely valuable tool. Furthermore, the study has identified the potential for hand-held technology to make this imaging modality widely available at a potentially low cost. Care providers should keep in mind barriers to use, including patient and provider perceptions, level of skill, power availability, and the lack of technical repair when designing ultrasound related programs on a global basis.

Limitations

There were several limitations in this study. LMIC economies as defined by the World Bank differ from year to year; therefore, the countries identified in 2018 may not include relevant countries from previous years, or include countries recently added to low or lower-middle economies. The Cochrane risk of bias assessment tool found that nearly one-half of the novel ultrasound research in the form of randomized controlled trials had a high or medium risk of bias, therefore conclusions derived from those specific studies should be considered carefully. Our definition of ‘novel ultrasound research’ involved some subjectivity and may represent biased inclusion of studies in this category. We attempted to minimize this bias by double-screening for inclusion. Finally, this study consists of a 9-year time frame, so may not capture longer-term trends.

Recommendation for Further Studies

We recommend further study promoting global collaboration, especially with inclusion or leadership by authors affiliated with institutions within LMICs, potentially still in collaboration with or funded by external institutional partners. Furthermore, the majority of studies were conducted within four countries (India, Egypt, Pakistan and Nigeria), and were performed at tertiary care centers. Further studies in lower-income economies and within district hospitals or community healthcare centers would broaden our scope of knowledge of ultrasound applications and adaptability to low-resource and rural settings.

5. Conclusion and Global Health Implications

In conclusion, this literature review focused on ultrasound trends and usage in LMICs. With the decreasing cost of ultrasound equipment and increasing availability of handheld ultrasound devices, it is important to continue assessment of the adoption and effective novel application of ultrasound technology in LMICs. Furthermore, there is a pressing need to address the potential capabilities and delineate limitations of ultrasound within resource limited settings. We found evidence of the role of educational training programs increasing screening and diagnostic clinical decision making. We also found the increasing adoption of ultrasound technology globally.

Compliance with Ethical Standards

Conflicts of Interest: No known conflicts of interest. Financial Disclosure: No relevant financial disclosures. Funding/Support: No funding or support. Ethics Approval: This review was exempted from IRB review. Acknowledgements: Non additional.

Key Messages

- Ultrasound related research and associated applications of this technology in LMICs has increased over the past decade.
- The role of educational training programs increasing screening and diagnostic clinical decision making was identified.
- There is a need for greater global collaboration in addition to higher quality ultrasound related research in LMICs.
References


