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Perspective

Point-of-care ultrasound for tuberculosis management in Sub-Saharan Africa—a balanced SWOT analysis

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ABSTRACT

Point-of-care ultrasound (POCUS) is an increasingly accessible skill, allowing for the decentralization of its use to nonspecialist healthcare workers to guide routine clinical decision-making. The advent of ultrasound-on-a-chip has transformed the technology into a portable mobile health device. Because of its high sensitivity to detect small consolidations, pleural effusions, and subpleural nodules, POCUS has recently been proposed as a sputum-free likely triage tool for tuberculosis (TB). To make an objective assessment of the potential and limitations of POCUS in routine TB management, we present a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis based on a review of the relevant literature and focusing on Sub-Saharan Africa (SSA). We identified numerous strengths and opportunities of POCUS for TB management, e.g., accessible, affordable, easy to use and maintain, expedited diagnosis, extrapulmonary TB detection, safer pleural/pericardial puncture, use in children/pregnant women/people living with HIV, targeted screening of TB contacts, monitoring TB sequelae, and creating artificial intelligence decision support. Weaknesses and external threats such as operator dependency, lack of visualization of central lung pathology, poor specificity, lack of impact assessments and data from SSA must be taken into consideration to ensure that the potential of the technology can be fully realized in research as in practice.

Introduction

Point-of-care ultrasound (POCUS) is an increasingly accessible skill, allowing for the decentralization of its use to nonspecialist healthcare workers to guide routine clinical decision-making. The advent of ultrasound-on-a-chip has transformed the technology into a portable, pocket-sized mobile health device while retaining an acceptable diagnostic performance and the versatility of their costly and cumbersome predecessors. (Rothberg et al., 2021). Owing to its ease of use, affordability, and low maintenance and consumable requirements, POCUS has emerged as an attractive skill in resource-limited settings, where out-of-pocket special-

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ist care and inconsistent radiology services erode health equity (Yadav et al., 2021). Its potential to be integrated into the standard clinical exam analogously to the stethoscope is already well recognized (Abrokwa et al., 2022; Andersen et al., 2019).

There is already moderately strong data to support POCUS of the pericardium, pleural space, and abdomen to detect extrapulmonary tuberculosis (ePTB) in people living with HIV (PLHIV) (Bobbio et al., 2019; Griesel et al., 2019; Kahn et al., 2020; Schafer et al., 2019; Van Hoving et al., 2020). In a recent review on rapid sputum-free diagnostics for active TB, POCUS of the lungs is proposed as a likely triage tool. (Nathavitharana et al., 2022).

However, there is the potential that the introduction of new diagnostic tools can inflate expectations and lead to interpretations beyond competence, resulting in incorrect conclusions. To make an objective assessment of the potential and limitations of POCUS in routine TB (ePTB and PTB) management, we present a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis based on a review of the relevant literature and focusing on Sub-Saharan Africa (SSA).

Strengths

Rapid differential diagnosis of respiratory syndromes

POCUS is established as a reference standard for the point-of-care assessment of many cardiopulmonary conditions. It is widely used by emergency physicians to evaluate patients with dyspnea (Qaseem et al., 2021), and when integrated into routine care, it significantly expedites diagnosis (Laursen et al., 2014). Its potential to differentiate cardiogenic and pulmonic dyspnea is well documented. Lung ultrasound (LUS) is highly effective in detecting lung consolidation in pneumonia (Chavez et al., 2014), and guidelines recommend LUS as an alternative to chest X-ray (CXR) for pneumonia diagnosis (Ewig et al., 2021). It also has excellent sensitivity (98-100%) for the detection of pleural effusions (Qaseem et al., 2021) and allows clinically useful characterization of its volume and content. The potential of LUS in diagnosing PTB is increasingly recognized. A recent systematic review (Bigio et al., 2021) showed that the presence of subpleural nodules had the highest sensitivity ranging from 73-100%.

Its excellent sensitivity to detect even sub-centimeter lesions seems to make LUS a promising triage tool to better identify patients who need further microbiological testing.

Rapid visualization of pericardial effusions

In SSA, an estimated 64-70% of pericardial effusions are because of TB, and up to 85% in PLHIV (Isiguzo et al., 2020; Ntsekhe and Mayosi, 2013). Confirming the diagnosis of TB pericarditis in resource-limited settings is difficult because of the poor availability of advanced laboratory analysis (Pankuweit et al., 2005). Thus, the diagnosis is most commonly suspected on a clinical basis.

Although complete echocardiography remains firmly in the domain of experts (Kimambo et al., 2021), the specific skill of identifying pericardial effusion has high diagnostic accuracy in POCUS-trained physicians, with a sensitivity and specificity of 89-91% and 96%, respectively (Chamsi-Pasha et al., 2017).

Improving the safety of pleural and pericardial interventions

Once pleural or pericardial effusion is detected by POCUS, it can be used to improve the safety and efficacy of thoracocentesis or pericardiocentesis for diagnostic or therapeutic purposes (Maggiolini et al., 2016; Peabody and Mandavia, 2017). Ultrasound is the only imaging technique that allows real-time visualization of the procedure and characterization of fluid content (loculated, purulent, or hemorrhagic versus noncomplicated). In addition, volume estimation can be made and a basic appreciation of the heart function (e.g., in the case of abundant pericardial fluid).

Accessibility and affordability

POCUS can fill the imaging gap where radiology services are absent, as is the case for virtually all basic or advanced healthcare centers in low-income countries (Yadav et al., 2021), or unaffordable, such as in countries without universal health coverage where patients rely on out-of-pocket expenditure for clinical exams. Ultrasound-on-a-chip probes are less costly than their piezoelectric predecessors and can be used with different types of smartphones (including some low-end editions) and tablets (Harrington, 2019). Even the lone consumable of ultrasound gel can be produced locally from a simple mixture of corn or cassava starch and water (Aziz et al., 2018; Binkowski et al., 2014).

Weaknesses

Operator dependency

Operator dependency is a well-substantiated criticism of POCUS. (Conlon et al., 2022) Although the acquisition is relatively simple, interpretation suffers from inter-user bias, with results varying across experience. This is further compounded by nonstandardized nomenclature and acquisition protocols.

Central lung cavities are undetectable

As air reflects ultrasound, the aerated lung is an impenetrable barrier to POCUS assessment, limiting the depth of LUS to the pleural line and adjacent pathology. Deeper structures that do not communicate with the pleura, such as central consolidations or lung masses, remain invisible. For TB, this implies that an isolated central cavity cannot be detected.

Lack of specificity of POCUS signs

Only one study (Montuori et al., 2019) reported on the specificity of LUS for the detection of PTB, with 67% for the presence of subpleural nodules.

Subpleural nodules are frequently found in lower respiratory tract infections irrespective of etiology (pulmonary TB, COVID-19, bacterial pneumonia, and pneumocystis pneumonia) (Bigio et al., 2021; Giordani et al., 2018). It is possible that more complex diagnostic patterns exist outside the capacity of human visual discernment, and thus specificity could be boosted by auxiliary deep learning tools or through synergy with cumulative imaging findings and complementary clinical and epidemiological signs. A large prospective SSA-based trial has been launched to evaluate the diagnostic performance of LUS for lower respiratory tract infections, including TB (Triage Ultrasound in TB-endemic Regions: TrUST) (Suttels et al., 2022).

At the moment, however, it should be clear that LUS alone cannot replace microbiological diagnosis but rather guide further testing for TB.

For the detection of ePTB, the Focused Assessment with Sonography for HIV-associated tuberculosis (FASH plus) protocol looks for pericardial effusion, pleural effusion, deep abdominal adenopathies, focal splenic or hepatic lesions and ascites (Heller et al., 2012) has clinically useful specificity, especially when two or more concurrent signs are present. (Kahn et al., 2020; Ndege et al., 2019; Van Hoving et al., 2020). A systematic review including 774 patients from Spain, the USA, Argentina, and South Africa found that 21% (95% confidence interval [CI] 10.6-33.8) of patients infected with HIV presented with splenic micro-abscesses of which 88.3% (95% CI 72.3-97.9) were because of TB.

Opportunities

TB during pregnancy and pediatric TB

To avoid radiation exposure to the fetus, LUS has come forward as an alternative first-line imaging tool in pregnant women with respiratory symptoms (Di Marco et al., 2015) and proved clinically useful during the COVID-19 pandemic (Kalafat et al., 2020).

Pediatric POCUS is also gaining popularity, partly motivated by its noninvasive advantage over radiation-based imagery. Studies are limited but indicate that POCUS may hold untapped potential for TB in the pediatric population with a lower yield of microbiological tests. A study supports this hypothesis, showing that ultrasound detected abnormalities more frequently than X-ray and that these abnormalities were more frequent in cases of PTB. Further, mediastinal ultrasound visualized lymphadenopathy, and children with confirmed PTB had larger lymph nodes than children with other respiratory diseases (Heuvelings et al., 2019). Finally, as ePTB is frequently found (30%) in children with confirmed or suspected PTB irrespective of HIV status, diagnosis may be assisted by FASH plus protocol. These findings suggest that POCUS can support the timely diagnosis of childhood TB and could optimize the triage of children for TB preventive therapy among those who are household contacts of confirmed patients with PTB.

It should be noted that the currently available ultrasound-on-a-chip devices are less suitable for children and mediastinal views (e.g., the head of the probe is too large for a suprasternal notch view) (Fentress et al., 2022).

TB in PLHIV

As for pediatric TB, point-of-care diagnostics for TB in PLHIV remain high on the World Health Organization research priority list (Gebreselassie et al., 2019). The FASH plus protocol is the most commonly used POCUS application in South Africa (Heller et al., 2012). As explained previously, the FASH plus exam evaluates six thoracic and abdominal areas in search for ePTB signs in PLHIV and showed a good performance in three SSA studies, notably increasing the probability of appropriate TB treatment initiation (Bobbio et al., 2019; Kahn et al., 2020; Van Hoving et al., 2020). Extending the routine clinical exam with a FASH scan can provide valuable clinical arguments to assist frontline healthcare workers in reaching the threshold for initiating TB treatment.

Household contact screening for active TB

As the sensitivity of LUS for the detection of (small) subpleural consolidations outweighs that of CXR (Chavez et al., 2014), the role of LUS as a low-cost mobile alternative to CXR in targeted case-finding for close contacts, including children and pregnant women needs to be explored, especially in light of the risk of overdiagnosis.

Follow-up of TB sequelae

The value of LUS for the follow-up and early detection of interstitial lung disease after COVID-19 seems of interest. Although being small and monocentric datasets, characterization of the sonographic interstitial syndrome seems to correlate well with computed tomography findings such as ground-glass opacities or parenchymal bands (Clofent et al., 2021). Where CXR offers a static impression of TB sequelae, LUS might be a complementary dynamic exam to help identify patients at risk for post-TB fibrosis, pachypleuritis, and superinfections. To date, and to our knowledge, there are no POCUS studies published on this population.

Artificial intelligence (AI) guided decision support

As discussed previously, ultrasound interpretation suffers from inter-user bias and is ultimately restricted by the human cognitive limits of pattern discrimination. This makes it a good candidate for computer-assisted decision support, where deep learning may help standardize and augment the predictive potential of this tool by guiding more objective interpretations and tolerating nonstandardized acquisition practices. The COVID-19 pandemic has cleared the path to deep learning applications of LUS (Zhao and Lediju Bell, 2022). However, no studies to date evaluate the performance of AI-POCUS interpretation for the diagnosis of PTB.

Threats

Lack of SSA data

Digital technology holds the potential to replace the missing resources of low-income settings, and SSA is becoming a “new breeding ground for global digital health” (Holst et al., 2020). Possibly the biggest threat is the sparse evidence of its utility in SSA populations and, thus, a lack of performance estimates to guide context-adapted interpretation. Indeed, it is currently unknown how the potentially confounding influence of PTB and its sequelae would influence POCUS performance. For POCUS adoption to be successful in SSA, its implementation should be integrated into local research efforts to cultivate a locally owned evidence base that will foster trust, understanding, and a level of caution.

Lack of trials showing an impact

All studies conducted to date are retrospective and prospective cohort studies. We need randomized controlled trials (RCTs) to show the impact and safety of the use of POCUS on patient management. For ePTB, a two-center RCT is underway in Tanzania to evaluate whether ultrasound in combination with other tests can increase the proportion of correctly treated patients. (Ndege et al., 2020)

Poor standardization of skills

POCUS is now rapidly being adopted by nonradiologist clinicians. Many studies, therefore, compare the skills of the clinician with that of the radiologist and often show encouraging outcomes (Strøm et al., 2020). However, these results do not guarantee safe POCUS practices. In 2020, the Emergency Care Research Institute (United States) identified POCUS as the second most important technology hazard in healthcare (Conlon et al., 2022). Overenthusiastic or unframed use of POCUS remains an important pitfall. Availability of training and standardized skill evaluation are essential quality control measures to develop safe practice. This is especially true for SSA, where gaining oversight is even more challenging because of a paucity of expertise and data collection constraints. To develop a context-adapted training program, it is important to promote an SSA ultrasonography community through which standardization can be strengthened by crowdsourced professional development and large-scale case-exchange networks. Accessible, continuous training and high-standard local expertise are essential for safe POCUS adoption.

Data accessibility, ownership, and privacy

Most POCUS devices can be configured to store images for Digital Imaging and Communications in Medicine or Picture Archiving

Figure 1. Schematic overview of Strengths, Weaknesses, Opportunities, and Threats for POCUS integration in routine TB care in SSA
POCUS = point-of-care ultrasound; SSA = Sub-Saharan Africa; TB = tuberculosis.

and Communication System. Some devices, however, pass through a proprietary cloud service that may raise questions about data privacy, sovereignty, and ownership. In SSA, many health workers communicate through diverse social media applications such as WhatsApp (Meyer et al., 2021). There is currently no framework in SSA for the safe sharing of medical images through these channels. Moreover, most other imaging is still stored in analog formats, such as printed x-rays which are given to the patient and thus not readily accessible or cataloged for long-term monitoring.

Unstable internet connection

In order to upload POCUS images from an ultrasound-on-a-chip device, a relatively robust and reliable internet connection is required. This is often unavailable, especially in remote areas, and it is important that POCUS applications provide access to extended or totally offline modes. They should also require a minimal update to guarantee longevity in the circumstances with a poor connection. Many conventional machines allow offline image transfer from the original device to external storage with a flash drive.

Especially for novice sonographers who are less sure or technically capable of capturing the most convincing still image, short ultrasound videos are often the most interesting and relevant to store or share but consume 1-2 Megabytes per recorded second. At an average cost of 0.5-35 USD per Gigabyte when working with mobile data in SSA (Alliance for Affordable Internet, 2022) this can rapidly become too expensive for local healthcare workers.

Sustainability of material and suitability for the tropics

POCUS devices have not been specifically designed for tropical weather conditions such as high humidity or extreme heat. Probes using ultrasound-on-chip technology have a tendency to overheat. This requires the user to interrupt the exam while the probe cools down. To our knowledge, there are no data on the sustainability and longevity of POCUS devices in the tropics. Successful adoption of POCUS will require robust devices adapted to SSA working conditions.

Nosocomial fomite-borne transmission

Ultrasound probes can play a role in nosocomial cross-contamination of infectious diseases through fomite transmission. Hospital hygiene is already challenging in SSA and requires massive coordination of consumables, training, and monitoring. (Ssekitoleko et al., 2020). Integrating hygiene awareness into POCUS training could be an opportunity to contribute to this critical issue.

Conclusion

Overall, this SWOT analysis highlights key factors for the successful integration of POCUS into routine TB care (Figure 1). POCUS is a valid candidate for technology frog-leaping in SSA and is reaching a tipping point in transforming the routine clinical exam of frontline healthcare workers. Strengths and opportunities are numerous. However, careful attention must be given to its various weaknesses and external threats to ensure that the potential of the technology can be fully realized.

Disclosure statement

The authors have no competing interests to declare.

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Ethical approval

Ethical approval is not applicable.

Author contributions

VS was responsible for writing the first draft and conceptualising the SWOT GA, AAF and APW conceptualized the SWOT JD, PM, BG, FA ,PT, ARH, FS, PV, GM and DC did the second revision EG and TB did the second revision and contributed to the standardization of skills issue, KK revised the pediatric section MAH designed figure 1 and wrote on AI guided decision support MAH and NBB are joint final authors and performed the final revision.

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