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Handheld ultrasound in austere, remote, and rural environments:

A review of the current state of the technology and a qualitative assessment of barriers to use

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1. **Abstract**

1.1 Background

This project thesis explores the unique potential of portable and handheld ultrasound technology in enhancing medical diagnostics in remote, rural, and austere environments. Despite its promise, widespread adoption faces notable challenges. This project thesis begins with a thorough literature review to pinpoint barriers to further use in resource-limited settings. Then, the thesis outlines a questionnaire that gathers the opinions of relevant medical professionals. These findings are complemented by semi-structured interviews, giving a deeper understanding of these barriers. The overarching goal is to delineate next steps towards broader implementation, ultimately aiming to enhance healthcare accessibility for patients residing in resource-deficit areas.

1.2 Methods

A broad literature review was conducted, encompassing articles, literature reviews, and textbooks up until 2021, while a more specific review was conducted for articles from 2021 to the present day. The primary objective was to identify key barriers to further implementation in resource-limited areas. A structured questionnaire was then sent to 20 healthcare providers meeting the inclusion criteria, garnering responses from 9 participants (45% answer rate). The questionnaire comprised 5 demographic questions, 3 general opinion questions, and 12 opinions on the most identified barriers rated on a scale from 1-5. Consenting participants were contacted for a follow-up semi-structured interview, of whom 3 responded, providing additional insights into opinions they expressed.

1.3 Results

The literature review highlighted many barriers, 12 of which appeared in multiple sources and were identified as significant challenges. The barriers are 1) expense, 2) medical specialization/education, 3) technological limitations, 4) training-acquisition, 5) maintaining proficiency, 6) portability, 7) time-restraint, 8) unacceptable inter-operator variation, 9) data-concerns, 10) administrative issues, 11) low sensitivity/specificity, and 12) an insubstantial literature base. The questionnaire also asked general questions about the technology's a) usefulness in the workplace, b) usefulness in austere environments, and c) overall potential to overcome these barriers. Analysis of the responses showed significant agreement with 1 opinion (a), neutral-agreement with 5 opinions (b, c, 1, 4, 7), significant neutrality regarding 2 opinions (5, 8), neutral-disagreement with 2 opinions (2, 3), and significant disagreement with 5 opinions (6, 9, 10, 11, 12). Follow-up interviews highlighted details around some opinions.

1.4 Conclusion

This project thesis integrates insights from a literature review, questionnaire, and semi-structured interviews to highlight fundamental barriers hindering further use of handheld ultrasound in rural, remote, and austere environments. Understanding these barriers is crucial for devising strategies to introduce this potentially groundbreaking technology in regions lacking definitive diagnostic modalities. The aim is for insights presented in this project thesis to contribute to ongoing discussions about enhancing healthcare accessibility in resource-limited areas by offering suggestions for the successful implementation of handheld ultrasound use in rural, remote, and austere environments.

2. Introduction and Background

Portable ultrasound technology has significantly impacted multiple fields of medicine, earning the moniker "the visual stethoscope of the 21st century".[1(p1)] This comparison, however, does not fully capture the nuances of this advancement. With low-radiation applications across various organ systems and pocket-sized portability, it provides a real-time window into the inner workings of the patient's body in nearly any setting imaginable. This insight, previously inferred solely through findings in the physical exam or obtained through more invasive imaging, has the potential of improving sensitivity and specificity in many medical diagnoses. Furthermore, it creates opportunities for real-time procedural guidance beyond hospital settings. Despite clear potential, the recency of this technological development translates to a limited literature-base. Therefore, current use of handheld ultrasound in austere environments relies on a good deal of intuition to fill in the gaps. While guidelines on use in these environments lack the same level of quality-assured topics in medicine, recent literature showcases providers employing this tool in novel environments that are practically inhospitable for more advanced medical technology.

The first section of this thesis attempts to give a succinct review of the documented use of portable-/handheld-ultrasound in austere, remote, and rural environments, from when it first appears in the literature up to the present day. As with any review in a developing field, it presents many holes in the current literature. This thesis then attempts to fill one such hole. The following section will focus on the limitations of use, bringing up a series of hypotheses regarding the specific barriers of use in specific regions of the world. In an attempt to test these hypotheses, the thesis will outline a qualitative questionnaire and follow-up interviews, exploring the opinions on the technology held by practicing doctors with experience in rural or resource-limited areas.

2.1 Clarification on terminology

Moving forward, when writing about 'the technology,' the author is referring to a portable version of an ultrasound probe that connects to a portable computing device. The most common iteration seen at the time of writing in 2023 is a multi-window probe that connects to a smartphone, which thereby becomes an ultrasound device. 'Portable-ultrasound' appears to be the term of choice for the technology in its earlier days, while 'handheld ultrasound,' 'point-of-care ultrasound' and 'POCUS' dominate in more recent literature. In accordance with the era, the term has some relevance for the level of technology. As an example, authors using the term 'portable ultrasound' in pre-2010 literature are often referring to a technology before smartphones became an element of the technology. The device is therefore portable by the day's standards, though not pocket-sized. On the other end of the spectrum, when an author uses the term 'handheld ultrasound,' he or she is almost exclusively referring to a type of handheld ultrasound apparatus that plugs into a smartphone. POCUS appears to be a middle-ground in many cases, sometimes referring to a handheld device and other times referring to a larger ultrasound apparatus on wheels, that is thereby portable within the confines of a hospital. Going forward, the author will be primarily using the term 'handheld ultrasound' when referring to the technology in its most portable form, as this is the focus of this thesis. If an aspect of the technology is relevant, it will be specified and not solely implied by the term used.

Another important distinction to make is that about the setting of technology usage. 'Austere environment' is the catch-all term of choice in the majority of the literature. Some literature deals with specific austere environments, preferring labels to denote that setting, such as 'pre-hospital,' 'combat,' or 'disaster-zone'. However, in most of these texts, the term 'austere' is brought up to describe the setting at least once. It will therefore be used henceforth as a term to refer to a patient-care situation that, due to location, terrain, weather, or other uncontrollable factors, becomes resource-limited. This can include remote, rural, or tropical clinics, as well as mountain expeditions, war zones, disaster settings, and so on.

A final important distinction to make is that between POCUS and RADUS. Point-of care ultrasound is an assessment meant to be an extension or supplement to the physical exam of a provider at the bedside of a patient.[2] The provider will often pose yes or no questions about the patient's condition and then use the ultrasound apparatus to potentially find an answer to that question. The focus in a radiological ultrasound assessment is different, as the level of training in seeking out pathology can be profoundly higher. In this case, a radiologist can use ultrasound (and other imaging) to search for pathology, often using a thinner base of clinical information on the patient. This distinction is important to make as the point-of-care ultrasound assessment is by no means meant to replace radiological expertise. This becomes increasingly important to underline in areas of the world where there is pushback against the use of handheld ultrasound, sometimes coming from within specialties that are concerned about having their area of expertise infringed upon.

2.2. The development of handheld ultrasound – a summary of previous literature

Point-of-care ultrasonography rests on a foundation of documented use of ultrasound in emergency departments across the globe. Through the late 20th century, ultrasound machines became smaller and more affordable, allowing machines to be introduced in higher volume, and thereby used in more diagnoses and procedures. This field is well mapped out and is succinctly outlined by Arienti and Camaggi, describing the myriad applications of the technology in evaluating the acutely ill or injured in a hospital setting.[3]

Around the turn of the century, is where the technology's potential use in resource-limited areas makes its debut in the literature, primarily under the term 'portable ultrasound.' As early as 1999, when evaluating the utility of ultrasound in trauma patients, there is mention of potential usefulness of ultrasound in more rural settings should the technology become more portable.[4] Throughout the first decade, there are increasing number of publications including handheld ultrasound in their methods and testing its limitations, being used as a tool for screening anterior-chamber depth in East Asia,[5] testing and confirming feasibility of transmitting images of a FAST abdominal assessment from combat-frontlines,[6] and demonstrating potential use in ruling out pneumothorax in combat.[7] One group of authors brought a handheld ultrasound device on a humanitarian mission following devastating mudslides and demonstrated the usefulness of the technology in ruling-in and ruling-out various conditions.[8] This study demonstrates a departure from the previous years of literature, being the first study of its kind where the authors utilize a handheld device in a truly austere, post-disaster environment, where there may have been challenges using a portable, but not handheld, device. In their 2009 study, Otto et al. introduces two interesting aspects to the literature.[9] First, the authors demonstrate successful use of the technology in a truly extreme environment, the top of Mount Everest. Second, they demonstrate the viability of telecommunication with expertise on the other end. This, they explain, is a novel element to the technology that allows an expert healthcare professional to telemetrically analyze the results in real-time in patients who find themselves in resource-limited environments. Three further studies focus on using handheld ultrasound to diagnose long-bone fractures, also exploring using inexperienced non-physician operators in the prehospital and combat environments. [10–12]

In the next decade, many more relevant studies were published. The usefulness of portable/handheld ultrasound is further demonstrated in field-medical operations,[13,14] a humanitarian disaster in Haiti,[15] diagnosing a pediatric patient in Haiti with intussusception,[16] utilizing telesonography from rural and remote environments,[17,18] rural emergency departments in Canada,[19] and improving WHO algorithms for recognizing pediatric pneumonia.[20] Haider et al. published the first study that introduced randomization to assess if there is a clinically-relevant difference in image quality, concluding no significant difference and that this has relevance for the resource-limited setting.[21] Further studies depict cases where findings from handheld ultrasound changed management decisions: on a medical mission trip in rural Nicaragua,[22] in the care of 2 neonates in the Philippines,[23] in a rural east-African emergency department,[24] and on a cruise-ship at sea.[25]

A handful of reviews have mapped out certain aspects of the technology's use and limitations in austere environments, citing and detailing many of the aforementioned studies. In 2016, Becker et al. published the first truly comprehensive on the subject, analyzing all English-language publications in major journals concerning use of handheld-ultrasound in low-to-middle income countries (LMIC).[26] They outline many potential uses of the technology as well as case-reports that demonstrate promising results. They underline, however, the need for more randomized-controlled trials to come to a definitive conclusion regarding the technology. Then in 2017, authors Gharahbaghian et al. detail specific usage areas and limitations with specific austere environments followed by a guide on specific techniques and assessment protocols most often used in austere environments.[27] The review discusses all relevant studies that include POCUS in combat, flight, natural catastrophes, tropical environments, outer-space and high-altitude. While most of the review is devoted to outlining the various applications of the technology in the respective environments, it presents an overall red thread of challenges, underlining technological issues related to the battery, hard-drive, and overall durability as the primary challenges to use in austere environments. Regarding military and combat environments, they point to temperature fluctuations, dusty/sandy environments and the rough handling as specific challenges in warzones in Iraq and Afghanistan.[27]

More recently, Canepa and Harris published a review also focusing on the use of portable ultrasound specifically in austere environments.[28] They start by outlining some technological aspects of the devices currently on the market. They also explain potential advantages of and uses for the technology in the evaluation of pulmonary, ocular, vascular and traumatic patient presentations as well as considerations specific to the post-disaster and tropical settings. They lay out a series of current limitations for the technology relating to concerns around its durability and electronic functionality in the truly austere environment, as well as issues tied to ultrasound as a modality such as difficult visualization in obese patients and inter-operator variability. They identify the primary gaps in the literature being that most studies in their review had small sample sizes and lacked measures to prove improvement in clinical outcomes.[28]

Expanding upon the preceding research, the most recent systematic review relevant to the subject-matter investigates the application of POCUS in resource-limited healthcare settings, exploring the potential for use in rural and remote environments in developed countries, including Australia.[29] Their overall conclusion is that the evidence they reviewed endorses the application of limited portable ultrasound use in settings that lack diagnostic ultrasound capabilities from before. They posit that this approach has the potential to enhance health outcomes in underserved communities in Australia and other regions as well, though they cite a need for a broader literature base on the subject.

As recent as 2021 a compilation of reviews was published outlining the current state of handheld ultrasound usage in emergency medicine in the United States[30]. The conclusion of these reviews is that the benefits of recent technological advancements are undeniable, though the authors also outline specific challenges and areas that require further research. They stress that these must be addressed before there is widespread implementation. The authors outline many benefits such as having an imaging device available for every patient encounter, a relatively low price-point, battery power not dependent on a centralized power source, similar image quality as cart-based systems, a reduced barrier-of-entry, and opportunities for tele-ultrasound and remote guidance.[30] These benefits are not without their challenges. The authors raise questions about the storage of images as it related to billing and patient confidentiality, as well as indicating that with their portability comes the natural disadvantage that the devices are more likely to be misplaced or stolen. As a solution to these issues, the authors bring up the importance of hospital-ownership of the devices with password protection and management software.

In 2021, Dr. Larry Istrail, M.D. released his literal manifesto on POCUS.[2] As an avid advocate of the technology, he outlines his case for further implementation of point-of-care ultrasound, specifically in cardiology and pulmonology. While a clear bias permeates the text, the author outlines a thorough search through the literature for all positive representations of POCUS within these respective fields. The book sets POCUS implementation in a historic context, framing it as the next big breakthrough in modern medicine, likening it to the implementation of the stethoscope 200 years ago. The comparison to the stethoscope ends up being a red thread in the text, being often used as a benchmark that POCUS supersedes in all areas of comparison. The author uses numerous studies to demonstrate this POCUS superiority, at times also bringing in other modalities such as the chest x-ray. He outlines improvements in sensitivity and specificity in cases of pulmonary edema, pneumonia, pleural effusions, assessment of the jugular vein, evaluating various pressures within the cardiopulmonary circuit, pericarditis, pericardial effusion and cardiac tamponade.[2] There are some cases where the author takes a step further, to even suggest that it would be irresponsible to not incorporate POCUS into the assessment, as the sensitivity or specificity of the traditional physical exam is woefully low, such as in the evaluation of pericarditis.

Though the book is overwhelmingly positive to widespread POCUS implementation, the author uses a concluding chapter to address some common criticisms.[2] He introduces one criticism as the quality of the assessment being dependent on the skill of the operator, and thereby prone to confirmation bias. His rebuttal to this, however, is that one could form the exact same argument about the stethoscope. The next common argument he introduces is the often-mentioned need for more of an evidence-base before the technology can be incorporated into practice. He counters this by explaining that a requirement for an evidence-base before implementation is a standard for medical treatment, though not necessarily for a diagnostic modality. His point being that medical treatment and diagnostic modalities do not need to be held to the same standard before they are implemented. The next argument he brings up is the notion that a reliance on gadgets allows clinicians to be lazy and rely less on critical thinking skills. He acknowledges some truth in this, though he explains that the argument is based in a flawed assumption that there is solid data to support the preconceived notions that a traditional physical exam conducted by an experienced physician has absolute superiority in sensitivity and specificity. He then brings up the argument that POCUS images are often obtained without formal documentation and may not be as readily accessible for quality assurance or retrospective analysis. While he recognizes that this may be the case in some instances, he counters by saying that this is a criticism of the person using the tool and not the tool itself. The next argument against regular implementation of POCUS is a lack of quantitative clinical outcomes in POCUS research, such as time to treatment initiation and time to discharge. He counters again with a familiar point, saying that these also lack for the stethoscope, and despite this, it is ubiquitous in medicine. The final argument he brings up cites a group of cynics who believe that the introduction of this technology into regular-use will diminish the physical exam and thereby erode the patient-doctor relationship. Thus far, there is little research to either confirm nor deny this point of view. Istrail brings up, however, one study that has actually shown the opposite: that introduction of the ultrasound into the physical exam actually improves the doctor-patient relationship in around half of the consultations.[31] He does, however, underline though that the area of patient perspectives of POCUS is an area that requires further research.

Also published in 2021, is thus-far the most extensive review of ultrasound-use in settings outside of the hospital: The Manual of Austere and Prehospital Ultrasound.[32] The textbook details considerations for a variety of prehospital and austere environments, followed by sections on all relevant diagnostic studies, applications in patient monitoring, as well as relevant ultrasound-guided procedures. The final sections review the practical matters of establishment of a training program and the proper care of equipment. Each section is written by one or more experts in that specific field of ultrasound-use, coming to a total of 49 contributors. Despite the large number of contributors, it is worth mentioning that all but one of the contributors practice in the United States, and the overwhelming majority work within Emergency Medicine, conferring a potentially significant bias to the text.

The text is primarily devoted to explaining the various uses of ultrasound in out-of-hospital settings, first outlining the literature base often from in-hospital studies, followed by a detailed explanation of relevant techniques or procedures. The potential benefits and uses of this technology permeate the text. Specifically with regards to helicopter emergency medical services (HEMS), Rodman and Jensen write about the possibility of reducing morbidity and mortality by using ultrasound to identify conditions that require immediate intervention. [33] This applies especially in trauma and acute medical or surgical conditions, which constitute the majority of cases in HEMS. The authors also outline how portable ultrasound can assist in the diagnosis of undifferentiated patients, contribute to better-informed clinical decision-making, and provide procedural assistance under transport.

The following section on military operations and prolonged field care represents handheld ultrasound as potentially the most important development in their medical capabilities in the current era.[34] This is due to the recognition of increasing numbers of possible uses combined with an increased complexity in their medical missions, leading to an increased reliance on triage based on more accurate clinical information. Key elements the authors underline as crucial for the technology's use in military field operations are ruggedness of the device, a balance between longer-battery and portability, capability to be powered by local infrastructure, and telemedical capability. While touting the general usefulness of the technology in their operations, they specify a few applications that could prove useful especially after establishing a larger literature base. These areas include the assessment of thoracoabdominal trauma, foreign-body location and removal, ocular ultrasound and assessing pulmonary edema in absence of radiography.

With regards to the specific austere environment met by a USAR team, the authors recognize specific advantages to point-of-care ultrasound.[35] Specifically, the fact that most of the patient evaluations occur in a confined space gives this technology a clear advantage in evaluation of a patient's clinical change over time. The authors explain that this helps with long-term decision-making in rescues that have prolonged extrications, plus conferring the advantage of providing clinical information despite the low-lighting, high-noise setting. The authors go on to discuss specific clinical indications for the technology's use, such as undifferentiated shock, crush syndrome and undifferentiated dyspnea. They conclude respectively that assessments for these conditions can give valuable information on the overall condition of the patient, assist with patient triage, and can supplement the physical assessment, especially in such an environment where auscultation may not be possible due to noise levels. The overall conclusion of this section is that the introduction of FAST and other POCUS protocols are likely to become more widespread in the future of USAR operations.

The final section of nearly each of these chapters identifies gaps in the literature as well as barriers for technology-use. Some recurring themes are as follows: costs related to equipment acquisition and maintenance, the training of personnel, quality assurance, oversight and protocol development that may be restricted for certain situations or services.[32] It is mentioned that cost may be the primary factor specifically for prehospital emergency medical services, where the cost may supersede the potential benefits to patient care. In addition, the budget used on implementing an ultrasound program may come at the expense of training in other areas of medicine. There is specific mention that HEMS programs are already so expensive by themselves, that the added price tag of an ultrasound device can be prohibitive by itself. Further, training and quality assurance are brought up under the pretext of cost, but they also represent barriers in and of themselves, with regards to the time and effort that must be put into the two. As such, there is mention that there must be an exceedingly large level of physician involvement. Another barrier identified in multiple places in the text is space-concerns, something that prevents implementing the technology in certain services. This may be a larger barrier specifically with HEMS, whose rigs already have a limited amount of space, as well as a mandate to have all apparatuses secured within the cabin.[33] This consideration of mounting the ultrasound device within the unit comes up multiple times, citing challenges such as the increased difficulty of scanning certain body regions with a fixed device.

Further articles in the text bring up various indications to involve POCUS in the diagnostic process. The introduction of each article outlines its usefulness in the respective indication followed by a detailed methodology on how to produce the correct images for interpretation. The concluding section in each article brings up barriers, limitations, or areas for further research. With regards to the diagnostic application of POCUS in shortness of breath, the authors mention a need for further studies in pediatric populations as well as intubated patients.[36] With regards to the assessment of chest pain, these authors underline that prehospital and austere ultrasound is an emerging field with immense potential due to myriad reasons mentioned previously.[37] The main barriers that they recognize relate to the difficulty of acquiring echocardiography skills and the difficulty of getting diagnostic heart views in certain patient populations. The author responsible for outlining prehospital trauma ultrasound, potentially the most well-known field of handheld ultrasound use, underlines limitations mentioned in previous sections, having to do with cost, quality assurance of images, and training requirements.[38] She also cites a need for more literature demonstrating impact on clinical outcomes if it is to be establishes as a standard of care. With regards to the evaluation of undifferentiated hypotension, the authors speak overwhelmingly positively about the technology's potential impact, though they cite an importance of using it as a tool within the bigger clinical picture as well as recognizing that some interventions may be unavailable in an austere environment.[39] In the realm of abdominal pain, the authors recognize the need for more studies that could demonstrate the ability of non-radiologist sonographers in finding the appendix for the diagnosis or exclusion of appendicitis.[40] With regards to the diagnosis of ocular conditions in the out-of-hospital setting, the authors recognize a need for more studies in this environment as most studies take places within the hospital.[41] They underline a specific advantage of being able to measure optic nerve sheath diameter (ONSD) to assess ICP in an out-of-hospital context, specifically in austere environments where brain imaging may be lacking. The authors specializing in obstetric ultrasound recognize the thin literature-base of using POCUS in the prehospital setting for obstetric and gynecological evaluations.[42] Citing the strong literature-base proving the usefulness of eFAST protocols in trauma, the Crockett and Soucy[42] conclude that the "next logical step is to develop curricula and to research the utility of pelvic POCUS in austere settings." On the topic of skin and soft tissue evaluations with ultrasound, the authors come to similar conclusion as previous sections, where the potential benefit in the austere environment is immense, but validation studies are lacking and optimal models for education will need to be put in place.[43] In the field of orthopedics, the authors outline some literature in favor of the use of handheld-ultrasound in diagnosing long-bone fractures, while also recognizing the lack of literature surrounding fractures in smaller bones such as the wrist and ankle.[44] In a number of cases, they describe a demonstrated potential though a lack of larger studies to validate these diagnostic methods and procedures, such as ultrasound assisted long-bone reduction, ultrasound-guided nerve blocks, and other invasive orthopedic procedures. A common theme for many of the authors[32,44(p176)] is "paucity of validated literature demonstrating equal efficacy in the truly austere setting." The conclusion, however, is that despite these holes in the literature, being able to use ultrasound to assess pathology in the musculoskeletal system is essential for healthcare professionals working in an austere environment.

Currently, the primary modality of tracking clinical change over time in patients in resource-limited settings is via monitoring vital signs, so a series of authors have written articles on introducing POCUS ultrasound as a component in additional monitoring studies. Karasek and Leo[45] present ultrasound-informed fluid resuscitation as a possibility for improving patient outcomes, detailing the incorporation of a cardiac, IVC and lung ultrasound assessment. They conclude, however, that this has not been validated or documented to improve patient outcome prehospitally or in austere settings. The following section outlines potential implementation of ultrasound as an adjunct to current methods to confirm ET-tube placement.[46] The authors bring up familiar themes with regards to the advantages and disadvantages, with advantages such as portability, real-time feedback, safety and ability to concurrently assess for lung pathology, and disadvantages such as cost, time needed for training and quality assurance, and inter-operator variance in image acquisition. The authors stress that this technique should be used as an adjunct to other existing protocols in the pre-hospital environment, though they suggest that the technology could be invaluable where traditional methods for measuring endotracheal tube depth are not available. With regards to measurement of optic nerve sheath diameter in the assessment of possible increased ICP, White et al.[47] conclude that there is insufficient evidence to warrant its implementation in the prehospital setting. They do suggest, however, that it could be useful in austere settings where other modalities are not available. Regarding assessments of the bladder and urinary tract, Kranc and Gonzalez-Marques[48(p232)] stress the superiority of ultrasound, though they recognize the limited literature-base in austere settings stating, "there is clearly a need for more research in this area, however we feel the data obtained in a hospital environment would be easily reproduced in the field."

Ultrasound has proven to be incredibly useful in challenging procedures that benefit from visualization of the underlying structures, specifically, obtaining vascular access,[49] pericardiocentesis,[50] surgical cricothyroidotomy,[51] thoracentesis,[52] and nerve blocks.[53,54] Some authors mention that use in the prehospital setting will likely increase with increased portability and lowered costs. Other authors, however, mention little about the specific setting of prehospital or austere ultrasound-guided procedures, suggesting an area for further research. Specifically, Louka[52] explains that the current literature-base on thoracentesis is built on studies in primarily high-resource hospitals, though there is recognition that the technology could bring more advanced care to locations with less resources. His point being that we have yet to see how treatment of these conditions will be altered or affected in austere environments, though decreased cost and portability will bring new opportunities to care in the austere environment. Further, the authors responsible for upper-extremity nerve blocks describe a similar situation, where the growing body of evidence for using handheld-ultrasound guidance in these nerve blocks take place in the operating room under controlled conditions with expert operators who have access to additional resources.[53] It is described that findings of these studies have limited generalizability and can underestimate failure- and complication-rates in settings characterized by their lack of control, namely austere settings. Despite this, the authors cite several studies that show the use of the technology in peripheral nerve blocks in some out-of-hospital settings. In the following section, Granhom[54] clarifies how useful ultrasound-guided lower limb nerve blocks can be with the right indications, while also stressing how important it is with proper theoretic education, practical training and maintenance of skills. He suggests that proper use can reduce the incidence of PTSD and chronic post traumatic pain, though he admits that further research is necessarily to shed more light on this topic. Further, Granholm[54(p301)] acknowledges a familiar theme of "limited knowledge regarding the training needed to perform these interventions in an austere setting and the current success rates".

The final section of the textbook regards itself with the practical aspects of establishing a training program around this technology. Given a lack of educational standards, especially in the education for non-physician providers, the authors suggest an outline for an education program, while also suggesting the eFAST protocol as a good starting point for any program.[55] The following article suggests a number of proactive protective measures to ensure the longevity of equipment, while also addressing a few specifics regarding power-management, connectivity and data-storage.[56] The solutions and suggestions presented in these sections become especially applicable when discussing specific barriers to further implementation in various resource-limited settings.

2.3 Conclusion on the comprehensive texts on the subject

After a thorough review of current literature reviews and textbooks, there are some overarching themes that can be established. First, handheld-ultrasound use is becoming widespread, especially among American and Australian emergency-medicine specialists. Some providers have realized the potential relatively early on, testing what is possible in the field and documenting promising potential. These initial experiments are demonstrating handheld ultrasound to be a valuable tool in places where the use of other imaging modalities would be impossible. Finally, these texts show promise in telemedicine and training programs, potentially improving overall patient care with more investment. Moving forward, this thesis will attempt to address some gaps that have been identified in this overview. First, the following section will outline publications with stricter inclusion criteria pertaining to the austere environments since the last collection of relevant reviews in 2021, with a specific focus on the barriers to further use. Of the barriers identified in the literature, the thesis will then outline a qualitative assessment of the opinions of healthcare-providers with specific experience in this field. This section will attempt to underline which barriers are most pressing, (in)surmountable, or relevant for the practitioners who may use the technology.

3. Literature review of studies specific to handheld-ultrasound usage in austere environments to the present day

3.1 Methods

Prior to study initiation, a thorough literature review was conducted on the topic. What proved to be the most effective search was to group key search terms into the following:

- Group 1: Adjectives relating to the technology - "handheld, hand-held, portable, pocket, mobile, point-of-care"
- Group 2: Nouns relating to the modality - "ultrasound, sonography, POCUS"
- Group 3: Adjectives relating to environment - "austere, rural, remote, resource-limited"

Using only Boolean operators between the 3 groups without a phrase specification brings up hundreds of irrelevant results, so a phrase specification was deemed necessarily. A search was conducted with all combinations of the 3 groups of terms as a phrase specification. As Boolean operators do not function within phrase specifications, the final search function ends up being long, but gives results ensuring relevant studies go unmissed. Some specific combinations such as 'portable POCUS' have been excluded as the specific combination does not appear anywhere in the literature. A visualization ends up looking like this:

Search	Keywords	Records
S1	Handheld OR hand-held	20,168
S2	Portable	50,895
S3	Pocket	74,503
S4	Mobile	152,943
S5	S1 or S2 or S3 or S4	291,416
S6	Ultrasound	2,003,557
S7	Sonography	555,167
S8	POCUS	2,524
S9	"Point-of-care ultrasound"	4,205
S10	S6 or S7 or S8 or S9	2,009,109
S11	"S5 S10"	1,357
S12	Austere	1,420
S13	Rural	264,927
S14	"Remote environment"	112
S15	"Resource-limited"	13,488

S16	Tropical	240,838
S17	S12 or S13 or S14 or S15 or S16	507,281
S18	S11 and S17	97

The final reproducible search function is the following:

("handheld ultrasound" OR "hand-held ultrasound" OR "portable ultrasound" OR “mobile ultrasound” OR “pocket ultrasound”

OR "handheld sonography" OR "hand-held sonography" OR "portable sonography"

OR "handheld POCUS"

OR "handheld point-of-care ultrasound" OR "portable point-of-care ultrasound")

AND (austere OR rural OR "remote environment" OR "resource-limited" OR tropical)

The following search function was put through PubMed in June, 2023 and then updated in January, 2024, giving 97 total results. The results were put through a manual selection process shown in appendix III to fit the following criteria:

Inclusion Criteria	Exclusion criteria
• Handheld ultrasound used • Portable ultrasound used • Tele-ultrasound with real-time feedback from experienced provider • Setting: o Austere environment o Resource-limited o Extended pre-hospital o Rural or improvised clinic	• Pre-2021 • Non-English language • Focus on training or protocol-development • Biotechnology focus • Simulation/proof-of-concept • HH-POCUS as modality without discussion of limitations • Provider with limited medical education (exception regarding tele-sonography) • Non-portable ultrasound apparatus • High-resource setting • Study type: o Case report (n = 1) o Report, opinion piece or editorial

Studies prior to 2021 are excluded due to their inclusion in the comprehensive and relevant literature reviews and textbooks outlined in previous sections.[2,27,29,32] The aim of this literature study is to map out the field in the years leading up to the present day. By the nature of the search function using English terms, non-English studies are thereby excluded. An attempt was made to include a separate literature search detailing any relevant literature in the Norwegian language, though none was found that met the criteria. Many newer studies focus on training programs in various foundational POCUS skills such as e-FAST and a basic obstetrics scan. These studies are excluded due to a lack of focus on the technology itself, while more often focusing on aspects of training programs that present promise or barriers to future implementation. Given the solid literature base regarding in-hospital POCUS, this review aims to exclude all studies that take place within a high-resource definitive-care. One reason being hospitals and larger clinics have space for larger ultrasound machines, thus making handheld machines less impactful in their application. Some studies that take place in hospitals use RCT design to compare the quality of the handheld machines compared to the standard machines.[57] While important to the overall literature-base of handheld ultrasound, these types of studies and their implications are well-covered in recent reviews and textbooks.[28,32] The term 'prehospital' and associated terms was deliberately left out of the search criteria, as the studies this brought forward tended to focus on technology-usage in prehospital providers in an environment where the patient was then transported to definitive care. The focus of this literature search is to highlight key studies where handheld ultrasound technology is used to make decisions in definitive care in resource-limited environments. With the term 'high-resource setting' it is intended to exclude studies that take place at well-funded regional hospitals or centralized clinics where a regular ultrasound apparatus could be used. Other studies were manually filtered out, specifically those that either did not take place in a truly austere environment and articles that did not discuss the limitations of the technology.

3.2 Results

Author (s); Journal; Year; Country	Study design, population, sample and environment	Study aims	Methods and equipment	Relevant results, limitations and barriers-to-use identified
Bidner A, Bezak E, Parange N; *BMC Public Health*; 2023; Australia [58]	Cross-sectional questionnaire for rural practitioners. Clinician participants span a large spectrum of educational levels, degree of workplace remoteness and previous experience with ultrasound.	Analyze the current need for ultrasound in rural and remote Australia and assess the barriers to use of antenatal ultrasound.	Broadly advertised anonymous online questionnaire – unable to calculate total reach or response rate. Targeted healthcare clinicians who provide care in rural areas. Conducted descriptive analysis of the quantitative data and thematic analysis of the qualitative data.	Analyze 114 valid responses, identifying lack of equipment and inaccessibility of training opportunities as the primary barriers. Discusses increasing the scope of practice of nurses and midwives, as the use of POCUS is not permitted in these roles. Expanding POCUS into these roles has the potential to expand antenatal ultrasound opportunities to a much larger patient population in rural Australia, the authors suggest. Series of specific barriers to training identified as long distance to courses, travel expenses, lack of time, lack of staffing coverage during provider absence, and difficulty meeting supervision requirements. Participants report opportunities to use telesonography systems, but cite technical and logistical barriers to use, as well as citing a belief that the user must be an expert in order to operate the probe. The discussion also brings up administrative issues in the form of difficulty accessing centralized patient records that could have data on previous scan for comparison, as well a lack of reimbursement preventing some providers from doing more scans, tying also into the issue of cost.

Phillips H, Sukheja N, Williams S, et al; *Rural Remote Health*; 2023; Australia [59]	Exploratory study in 4 general practices located in rural south Australia. A total of 472 scans recorded.	Investigate the utilization of point-of-care ultrasound by physicians in Australian rural general practice.	Provided apparatus and training course to 4 general practices. Survey at commencement of study regarding prior experience. Gathering of user data, including types and frequency of scans.	The majority of providers report limited confidence in their findings. Authors underline the need for additional research to explore obstacles in the adoption of POCUS, specifically focusing on considerations around training, reimbursement, and accessibility to equipment.
Thomas O, Aruparayil N, Gnanaraj J, et al; *PLOS Glob Public Health*; 2023; India [60]	Multi-method study retrospectively reviewing 3 months of patient records and conducting 12 semi-structured interviews. The providers are in a mobile medical unit (MMU) in rural India.	Assess POCUS use in patients with suspected surgical abdominal conditions.	Utilized a health needs assessment framework to assess the requirement for POCUS in suspected surgical abdominal cases by comparing two remote outreach camps in rural India. The test-group had access to 2 devices, one stationary at basecamp and one mobile ultrasound device during outreach, both operated by 5 authorized radiologists. Qualitative data collected via semi-structured interviews conducted with members of both teams, later analyzed using framework analysis. Quantitative data collected via analysis of past medical records focusing on descriptive statistics, symptoms, diagnoses, and use of medical testing.	The authors describe limited patient knowledge about ultrasound, highlighting some patient's belief that ultrasound is either therapeutic or omniscient. This can lead to over-testing. There are issues surrounding reparation, that being inability to fix on-site and the uncertainty around time to repair when sending to an external site. This is tied into issues around durability, specifically damage done from travel over rough roads. Some practitioners use the technology for abortion based on gender-selection. There is a limited number of radiology specialists in an area where radiologist oversight is required to conduct a POCUS-examination, plus complex government regulations around ownership of POCUS-devices connected to radiology specialty. There is a described inability to implement potentially beneficial telemedicine programs, due to strict governmental regulations.

Arnold AC, Fleet R, Lim D; *Int J Environ Res Public Health*; 2023; Australia [61]	Qualitative descriptive study including interviews from 10 rural practitioners.	Identify and evaluate barriers and contributors to increased use of point-of-care ultrasound, specifically in rural Australia	Recruited rural clinicians with at least 12 months of work experience, using 3 different schools or agencies to find participants. Conducted 30 to 60 minute interviews. Utilized the Walt and Gilson health policy framework to analyze data from the interviews, using thematic analysis to categorize common themes. To ensure quality of research, an audit trail, reflective journal, member checking, multiple coding and peer review are all conducted.	The majority of the participants mention issues around cost. Specifically, recuperating cost after the initial investment proves difficult for some respondents, as they are unable to bill appropriately for this assessment modality. Maintenance of skills – connected to fear that providers not being able to interpret what they find. In addition, providers explain a rapid decline in skills as well as a difficulty transferring training over to clinical practice. Issues around training are identified as a major barrier. This includes a lack of access to or time for education, the costs association with training and concerns around the lack of educational standardization. There is mention of a lack of quality-assurance. This ties into the issue of accessibility that many rural providers cite as well as an inability to trust ones own conclusions from findings due to a lower volume of use. Some participants suggest remote support with an expert as a possible solution. Combination of rapid skill loss and lack of standardization is tied to the idea that there may be large inter-operator variability. The authors admit a limited degree to which these results can be generalized to other locations and contexts given the small group of rural Australian providers who were the focus of this study. They also report that the sampling methodology used may open for the possibility of selection bias.
Wanjiku G, Dreizler L, Wu S, et al; *Ultrasound J*; 2023; Kenya [62]	120 images were obtained by 5 participants. Participants are primarily novice POCUS trainees	Assess the utility of handheld ultrasound for image acquisition and interpretation by trained Kenyan providers.	Participants performed an OSCE examination on a healthy pre-screened volunteer directly after a refresher course in the e-FAST and focused obstetrics scans. The examination was performed twice, once with a handheld device (Butteryfly iQ) and once with a notebook ultrasound model common for the area.	Find no statistical difference comparing interpretation of images between a handheld device and a traditional device. Find a statistical difference when comparing e-FAST image quality between the two devices. Mention and cite the financial barrier as part of the background. Cite technological limitations as the primary complaint of the participants, specifically referring to the small screen size on the iPhones used with the handheld device, as well as lacking certain functionalities specific to measurements in obstetrics.

Kornelsen J, Ho H, Robinson V, Frenkel O; *BMC Prim Care*; 2023; Canada [63]	Qualitative study consisting of 21 interviews with family practitioners in rural Canada	Explore the opinions of rural family practitioners around the use of subsidized point-of-care ultrasound devices.	Invitation to study participation was sent to 50 recipients of a program that subsidized POCUS use, 21 of whom responded. Semi-structured interviews were conducted online covering motivation, training, previous experience, and communication with specialists. Interviews were processed using thematic analysis, and the results were subsequently viewed through Rogers' theory on the Diffusion of Innovation from 1962.	The authors code themes in the interview corresponding to all 5 of Roger's elements that determine the rate at which a new technology will be adopted: relative advantage, compatibility, complexity, trialability, and observability. The technological learning curve is identified as a barrier, both with regards to the practicality of implementation, but also how to incorporate it into situations where infection control needs to be accounted for. Many participants mention the danger of going on co-called "fishing-expeditions" and thereby uncovering a finding that they are unable to interpret or end up misinterpreting. Financial issues are brought up by many participants, tying into issues around billing-codes, increasing the length of consultations, maintenance of skills, the costs of the equipment and eventual obsolescence of current technology. Some providers expressed a feeling of a lack of support from specialists owing primarily due to protocols that specify reading only scans conducted by ultrasound technicians. Some participants mention concerns around liability regarding conclusions made from a POCUS scan as well as a lack of accreditation of training. Lack of formal oversight programs is recognized as being markedly lacking among rural providers. Some have proposed informal support networks as a solution. There is a clear bias described regarding the selection of participants being their relative over-enthusiasm for the technology compared to an average rural provider.

Elsayes AK, Rohren SA, Islam NB, et al; *Rural Remote Health*; 2021; Guatemala [64]	Retrospective observational study, where 205 patients were seen, of whom 24 (12%) received POCUS examination	Assess the efficacy of portable ultrasound imaging during a brief medical service trip (MST) to rural Guatemala.	POCUS used on indication by US-trained Emergency Medicine specialists in single-visit outpatient setting with possibility of remote conference with radiologist or cardiologist. Suspected diagnosis and plan recorded prior to and after examination. Retroactive analysis of data to assess frequency of management change in relation to POCUS usage.	The results of 13 (54%) exams altered medical management, and the remaining 11 (46%) exams confirmed the pre-test suspected diagnoses. Authors cite the following as limitations of the study: low number of enrolled patients, a significant selection bias, issues surrounding blinding, and no follow-up of patients. Expense and education are cited as the two major barriers to more widespread use of handheld ultrasound on a general basis.
Kodaira Y, Pisani L, Boyle S, et al; *Int J Gynaecol Obstet*; 2021;Sierra Leone [65]	Single-center, prospective observational study with 307 patients meeting inclusion criteria.	Assess the practical implications of handheld ultrasound devices in a resource-limited hospital with high patient-load.	Female patients evaluated in five frequently encountered clinical situations: early pregnancy vaginal bleeding, (pre)eclampsia, prolonged/obstructed labor, prepartum hemorrhage, and other high-risk pregnancies. Findings obtained with a POCUS device, then compared to experienced user using a conventional full-feature apparatus. Participants using POCUS are all trained physicians.	Handheld POCUS findings were deemed reliable for detecting pre-specified urgent obstetric findings in a high-volume, resource-limited referral hospital. Assessment of gestational age using BPD had the lowest agreement rate between handheld vs. conventional apparatus, as all participants failed to find at least one landmark. This leads to the authors to suggest further studies on continued training in these skills with handheld devices. They found the diagnostic accuracy of the studied conditions to be independent of operator experience. Authors cite a series of limitations: they did not perform sample size calculation or randomization; there was a possible selection bias and potential imbalance in patient recruitment, with overrepresentation of diagnoses typical for the prenatal clinic; there was little quality control of image quality.

Toscano M, Marini TJ, Drennan K, et al; *BMC Pregnancy Childbirth*; 2021; Peru [66]	Single-center pilot study enrolling 126 patients to 2nd and 3rd trimester scans at a health center in Lima, Peru.	Test the effectiveness of a novel, innovative obstetric telediagnostic system.	1 nurse and 1 care technician without prior ultrasound experience are trained to scan with simple protocols using external landmarks. Images sent to an off-site specialist for interpretation. Patients are concurrently scanned by a trained radiologist. Results compared statistically using Cohen's Kappa.	Exceptional agreement between the telediagnostic system and standard of care ultrasound, especially in recognizing number of fetuses, fetus presentation, placental location, and amniotic fluid volume. Recognition of gross discrepancies allows identification of patients for further follow-up. Attempts are made to take fetal biometric measurements, though the protocol does not always produce images in the right plane to produce these images to the same accuracy as the standard of care. Overall conclusion that these results show promise that the system could assist in increasing access to diagnostic obstetric ultrasound in low-resource settings, especially in situations where high-risk conditions can be identified early, allowing organization for transport to an appropriate level of care. Acknowledgement of a relatively healthy patient population, leading the authors to suggest further study into the feasibility of this method in recognizing a higher volume of pathology.
Sullivan JF, do Brasil M, Roman JW, et al; *Military Medicine*; 2021; Brazil [67]	Retrospective, observational analysis of the February 2019 Brazilian Riverine mission. Of 814 patients who presented for care, 24 were referred for POCUS evaluation.	Measure the utilization of POCUS and assess its impact on patient management decisions. Provide insights into the potential inclusion of POCUS in all military medical humanitarian missions. Estimate potential cost savings resulting from POCUS evaluations.	Direct and remote supervision of participating providers by another provider trained in POCUS. Recorded information about the type of scan, indication for the scan, findings, and if it changed management decisions.	In 10 of the 24 examinations, patient management decisions were influenced, leading to the prevention of unnecessary referrals, and thereby sparing a substantial cost and time burden for both the patient and the providing instance. The authors acknowledge that the cost of training in POCUS was not included into their cost-benefit equation, recognizing that these training costs can be prohibitive for providers who did not have this as a part of their medical training. The authors also recognize that their results may not be generalizable to other settings, plus that their study lacked follow-up of patients. They suggest future longitudinal studies to come to a more definitive conclusion on management changes based on POCUS findings.

3.3 Discussion - part 1

The first aim of this literature review is to update the specific literature-base that has to do with the intersection between handheld ultrasound technology and environments presenting unique challenges to practicing medicine. Following the current review, it is clear that the literature base still remains limited and rather specific, minimizing the ability to generalize or extrapolate results to other areas or applications not presently included in the literature base.[67] There is, however, a red thread in much of the literature that will be elucidated here.

The potential benefit of handheld ultrasound in these extreme environments appears to be well-established in the previous literature reviews[27,28,32], so that will not be the primary focus of this discussion. Instead, the focus will be turned to the limitations and barriers that these studies bring up in the hope of paving a way for some next steps, both in daily medical practice and with regards to further research and inquiry. This section will refer back to relevant literature that cites these issues as well as providing hypotheses for further inquiry under each barrier. Looking broadly over this literature review up to the present day, the top barriers to further use can be identified as follows:

1) <u>Cost of equipment</u>: The sheer expense of this modern technology prevents many providers from being early adopters.[63] This issue has been shown to be compounded in resource-limited care facilities in LMICs[62] though it is also brought up in the context of rural providers in well-developed health-care systems.[58,61] It is possible that this will not be a significant factor in providers who travel from high-resource workplaces to low-resource locations to provide care on a short-term medical-mission.
2) <u>Usage not being permitted outside of a specific specialty</u>: This barrier often comes up in the context of certain countries or medical governing bodies having restrictions against ultrasound use outside of the specialty of radiology. This could present unique barriers to use to providers who work full-time in these respective countries such as India.[60] This also has implications in countries where POCUS is permitted for all physicians, but is restricted for nurses and midwives such as in Australia.[58] It also appears that this notion can be an appendage in the opinions of certain specialists in countries that otherwise have relative widespread usage of POCUS in the frontline.[63] It is hypothesized that the significance of this barrier will depend entirely on the provider's country of practice and level of training, though providers travelling across

borders to provide care in resource-limited areas may be less concerned about these specific regulations in the host country.

3) Technological limitations and concerns about reliability: This was a recurring theme in the two major literature reviews, especially regarding combat-medicine [27,28] and remains present in more current literature as well. [60,62,63] Specifically, many rural practitoners reported "they were less inclined to use the technology when confronted with any technological perturbations." [63(p6)] Austere environments are, by their nature, unkind to fragile technology, so it is clear that it will take time before the technology meets the needs of providers in the most extreme environments. The weight a provider assigns to this barrier will likely depend in large part to type of environment the provider is travelling to and the degree of resource-deficiency in the area.
4) Difficulty in acquiring training: This appears as a challenge that seems to be tied to the specialization and level-of-training the provider has, with some having training included in their education and other having to seek training independently.[67] It appears that especially rural general practitioners have a difficulty acquiring training.[58,61] It is hypothesized that, despite rapid advancements in the technological aspects of handheld ultrasound, that this barrier may remain one of the top barriers for further implementation for many years to come. Diving deeper into the discussion of Bidner et al.,[58] it is clear that there is no one solution to this issue, being confounded by other barriers such as cost of travel, staffing issues and lack of time to invest in travel and training, given the majority of the courses are held in large cities.
5) Difficulty in maintaining proficiency: Tying into the previous point, it could be assumed that groups experiencing problems with acquiring training will also experience problems maintaining proficiency. It is proposed that there may, however, be certain groups of professionals that struggle more with maintaining proficiency, as diagnosis via ultrasound is a perishable skill and a single course in handheld ultrasound may not be sufficient to feel confident in one's findings.[59,61,63] A one-time investment in receiving initial training in the skill may prove to be less of a barrier than the more long-term effort required to maintain the skill, especially in a location with already limited opportunities for oversight and continuing education.
6) Time-restraints of providers: This barrier refers specifically to the lack of time practitioners have to devote to tasks in association with establishing a program for use such as creating protocols, training other providers or providing/receiving oversight.[55,58,61] This issue can also be tied into the inevitable consequence of

incorporating ultrasound into a clinical evaluation, making the consultation longer than intended.[63] Though it is not mentioned directly in the literature, it could be inferred that this barrier will remain, and potentially grow in the future. With the roles of many medical practitioners growing to encompass increasing areas of responsibility, it can be hypothesized that the time-restraints of these practitioners are going to become even more taxed. This stresses the importance of streamlining training-programs and protocol-formation as much as possible, while not sacrificing in quality, training providers and designing a service in such a way that provides an improved standard of care for patients in rural, remote, and austere environments.

These final six opinions have been identified in previous literature with solutions proposed in each case, though the opinions may still be held by some providers:

7) Issues regarding portability: This argument often surfaced in much of the early literature when ultrasound was becoming portable though not handheld. The issue is mentioned previous in connection with HEMS rigs[33] as well as in expedition medicine, where careful considerations around weight vs. benefit may end up excluding a portable device from the expedition.[68] This issue is not clearly emphasized in the newest literature and may not be expressed as strongly with current providers, possibly due to the newest developments in portability.
8) Unacceptable inter-operator variation: This opinion has been expressed multiple times in the older literature, [28,46] though it also appears occasionally in newer literature.[61] This is a challenge for the modality as a whole, though some studies present standardized protocols as a way to minimize this variation, especially with inexperienced operators using telesonography.[66] This barrier can be viewed with even less significance when using the framework of POCUS as an extension of the physical exam to answer a specific clinical question, as posited by Istrail [2] among others.
9) Issues around data-storage and patient-confidentiality: The portability and connectedness of these devices increases the ease of sharing images between providers which, in turn, introduces questions about potential violation of patient confidentiality. As the technology becomes more widespread, it is possible that there will be more solutions than hindrances regarding this barrier, as authors present an ever growing series of solutions such as encryption, de-identification of images, secure cloud-based platforms, and integration of ultrasound into already-secured forms of medical monitoring such as EKG- and vital sign-monitors. [56]

10) Administrative issues: This category is intended to cover a broad range of issues brough up in the literature such as patient-billing, device ownership, and protection of devices against theft. [56,58,63] It is hypothesized that these issues may not be the ones that front-line providers stress the most when evaluating the barriers to further use.
11) Unacceptably low sensitivity or specificity: Some literature states this as a commonly-held belief of practitioners who are skeptical to implementation of the new technology, though authors like Istrail have outlined in detail the various applications in which this belief can be challenged. [2] It is possible that this is still a widely held view, especially among healthcare providers who are unable to keep up with recent developments in the literature.
12) Insubstantial literature-base: It appears as though this is especially relevant when evaluating specific procedures and techniques regarding ultrasound in extreme environments, though as a general concept, there seems to be a substantial literature base regarding its general functionality in resource-limited environments. [2,32] It is possible that there could be significant variation in response to this opinion based on a provider's background.

4. A qualitative assessment of perceived barriers to use in providers working in rural and remote environments in the United States, Australia, Costa Rica and Indonesia

4.1 Methods

This element of the thesis is a qualitative cross-sectional analysis that explores the opinions of medical personnel with relevant experience. It specifically examines their perception of the barriers to use of this developing technology in resource-limited environments, using the results from the literature-review as a base for the questions. Given the nature of the questionnaire, exploring opinions of health-care personnel, it was determined that involving the ethics committee was unnecessary given that patient information is not collected or processed in the study. The objectives and procedures of the study are outlined in the introduction of the questionnaire.

Inclusion and exclusion criteria for participants were specified before sending out the questionnaire, and the first demographic questions assess whether the participant fits the criteria. For the responses to be included in the study, the participant must be a healthcare provider with experience in a rural, remote, austere, or resource-limited environment. The provider must also provide definitive care in one or more settings. The questionnaire was sent out in 2 rounds via a common contact-person for a group of employees/volunteers. Due to the nature of the position these providers have in common, it could be assumed that most participants would already fit within the criteria. The first-round of participants were contacted via a common contact working within the Australian College of Remote and Rural Medicine. The results of this round are only included as a semi-structured interview and not in the qualitative analysis of the questionnaire due to insufficient number of responses to the questionnaire. The second group of providers were contacted via a manager for a position that, in essence, automatically qualified the participants for the investigation given the nature of the position. The position involves providing medical care, two-weeks annually, in an extremely remote location with a high-density of especially trauma patients. More specifically, this position, titled ‘surf-medic,’ involves being an emergency medical provider at a surf-camp in an area with some of the most powerful and dangerous surfing conditions in the world. The position has a base requirement of being an experienced paramedic, nurse, or emergency-room doctor with experience in resource-limited environments. The manager sent out the questionnaire to the 20 providers on the recurrent list, meaning they have successfully completed multiple stints on location, providing emergency medical care to guests and the local community.

The content, phrasing and structure of the questionnaire went through two formal revisions before being sent out to the final group of participants. Questions were revised and format was improved following advice from an advisor with specialization in Emergency Medicine who has a vested interest in the topic. The second revision was made with feedback from a sample participant, who is a rural healthcare provider with experience with the technology. Responses were collected through the Google Forms service. This choice was made primarily in the interest of not using unnecessary funds on this project as well as the unnecessity of using a more data-protected service which would require payment.

Appendix II has a full overview of the questions, though an overview of the content of the questionnaire is as follows:

- 5 introductory questions to assess inclusion criteria and be able to group participants into type of medical provider, level of training, location of medical practice and experience with the technology.
- 2 questions grade the participant's overall opinion on the use of handheld-ultrasound. These and subsequent questions are graded on a scale from 1 to 5, 1 being 'strongly disagree' and 5 being 'strongly agree.'
- 12 questions assess the participants' opinion on the most cited barriers to more widespread use of handheld-ultrasound in.
- The final question assesses the participant's overall view if these barriers are surmountable.
- There is a final optional field where the participant can enter his or her e-mail address for a follow-up semi-structured interview.

4.2 Results

The questionnaire was sent out to a total of 20 relevant participants and 9 participants responded, leading to a response rate of 45%. In appendix I are a series of figures to represent the results from the questionnaire. Figures 1-4 give an overview of the participants with choice of visual representation made based on simplicity, using pie-charts for questions with one qualifier, and bar graphs for questions where the participants could choose multiple descriptors or locations. Figures 5 is a bar graphs, which was chosen as the most effective visual representation for the Likert data acquired in the questionnaire on the opinions the providers have regarding the use of handheld-ultrasound in austere environments.

Weighted averages were calculated for the questionnaire responses with error bars established using standard error with a 95% confidence interval. Figure 6 displays the results in a bar graph, showing the following regarding the 15 total opinions on the questionnaire:

- Significant agreement with 1 opinion: potential for use in the workplace.
- Neutral-agreement with 5 opinions: potential for use in austere environments, cost-prohibitive, difficulty in acquiring training, time-restraint, and barriers being surmountable.
- Significant neutrality with 2 opinions: difficulty maintaining proficiency and unacceptable inter-operator variation.
- Neutral-disagreement with 2 opinions: use not permitted outside a certain specialty and technological restraints/reliability.
- Significant disagreement with 5 opinions: portability, issues around data-storage and confidentiality, unacceptably low sensitivity or specificity, insubstantial literature-base.

Three participants offered up a follow-up semi-structured interview, one directly from the questionnaire, one who was a participant during the revision process and another from direct outreach in a rural location in Costa Rica. The findings are explained in a manner to maintain some anonymity of the participants.

One participant explains his situation when working as an RN in a medium-sized Australian city, where he and his colleagues received in-service training on ultrasound-guided IV-placement. However, due to professional scope-of-practice limitations for RNs, performing such procedures was not permitted. He explains further that the difficulty in acquiring training primarily arises from cost and time commitments, while the maintenance of proficiency, especially for US-guided IV-insertion, posed challenges due to the time constraints of the procedure and the lack of support for using the device in this specific emergency department. He believes that utilization will increase with significant revisions to guidelines supporting RNs and other specialties in utilizing the technology. With a growing number of individuals becoming proficient with handheld ultrasound, the pool of people available for support and education will thereby expand. This in turn, he believes, will lead to a growth in the body of available evidence for its benefits. Additionally, with technological advancements, he anticipates the emergence of high-quality, cost-effective machines.

Another participant describes that regarding the cost-barrier, he has no intention of personally purchasing the equipment. Concerning training, he asserts that any challenge can be overcome with sufficient motivation. Personally, he has not needed to take this step, given that he has access to comprehensive radiology services in his daily role as a general practitioner affiliated with a large hospital complex. His exposure to austere environments has primarily been at surf resorts, primarily dealing with minor trauma and lacerations that don't necessitate the clinical use of ultrasound.

A third participant explains his desire to incorporate handheld ultrasound into his practice, but explains that any clinical use of ultrasound is reserved to the specialty of radiology in his country of practice, Costa Rica. If he implements the technology in his practice in any way, he describes a risk of losing his license. When questioned on other commonly identified barriers to further use, he explains that high start-up costs and difficulty acquiring training are not factors in his hesitancy to use the technology in his practice. The sole factor for this provider is a so-called monopoly over ultrasound use that the radiology specialty has in his country of practice.

4.3 Discussion – part 2

As a continuation of the previous discussion section, this section will attempt to highlight the most relevant barriers to further use in a specific group of healthcare providers providing care in an austere environment, linking their opinions to barriers that appear repeatedly in the literature base. There was significant agreement with the opinion that there is potential for use of POCUS in the participants' workplace, an opinion that is also broadly represented in the literature.[3] It thereby appears to be a commonly-accepted opinion in medical providers who provide care abroad on a volunteer basis that POCUS is useful in various high-resource medical settings. Further, there was neutral-agreement with 5 opinions, that being an error bar comprising both agreement and neutrality regarding these statements. The results demonstrate this regarding the potential for use in austere environments, impact of expense, difficulty in acquiring training, time-restraint, and barriers being surmountable. Looking more specifically at the bar graphs, we see similar forms with the first three opinions, with primarily agreement and neutrality in responses, with a minority of participants disagreeing. Regarding time-restraint there is a larger split in the participants' opinions. Finally, regarding the barriers being surmountable, we see overall agreement in the participants, though the error calculation ends up wider, including neutrality, due to one participant expressing strong disagreement and one expressing disagreement. While the overall view of these providers is tilted towards seeing a potential use for handheld ultrasound in the austere environment, the participants identify cost, difficulty acquiring training and time-restraint as the most agreed upon barriers to further use. The general opinion is also tilted towards agreement regarding the surmountable of the barriers mentioned in this questionnaire, which shows promise for future use in this specific population.

Regarding the neutral stance on difficulty maintaining proficiency and unacceptable inter-operator variation, both seem to be due to a larger number of neutral responses combined with some responses splitting between agreement and disagreement, though with the latter leaning towards agreement. These two barriers remain inconclusive, as it would take a larger sample size to determine if the results demonstrate providers being entirely neutral on these stances or if there is a substantial split amongst providers regarding the significance of these barriers.

The barrier of ultrasound-use not being permitted outside a certain specialty has a split in responses primarily between strong disagreement and neutrality, giving a broad error bar that spans over disagreement and neutrality. This could be reflective of the fact that most of the participants come from high-resource settings in countries where POCUS is allowed, if not encouraged, in their professional work life. Potentially tellingly is the fact that the singular responses in strong agreement and agreement respectively come from a medical doctor in Brazil and a nurse in the United States. Though these are singular findings that would need to be confirmed in larger sample sizes, it concurs with similar findings in the literature review and interviews. The literature review depicts this being a barrier in India,[60] while a provider in Costa Rica interviewed for this project thesis explains the same barrier in his rural practice. It is possible that this participant has responded in such a way due to more such restrictions to POCUS use in Brazil compared to other participants who come from the United States and Australia where POCUS use is widespread outside of the specialty of radiology.[32] In a follow-up interview conducted for this thesis, a nurse explains this same barrier of POCUS being outside of the scope-of-practice for his role as a nurse in his current workplace. This is likely a barrier for many medical professionals without a license to practice independently, even in countries with ever growing POCUS usage such as the United States and Australia. Regarding reliability and technological concerns, the responses are relatively polarizing with a slight overweight towards disagreement. Here it is important to point out that the wider error bars include neutrality and disagreement, though the second most common answer choice is agreement. This split in opinions could be explained by the different expectations providers may have for the reliability of equipment, depending on the environment it is intended to function in.

The providers in this survey express overall disagreement with the impact of the five barriers: portability, issues around data-storage and confidentiality, administrative issues, unacceptably low sensitivity or specificity, and insubstantial literature-base. These all display relatively similar patterns on the bar graph, with portability deviating most from the others by having an overweight of providers strongly disagreeing with the portability of the technology being a barrier to further use. Interestingly, these five opinions were identified in the previous literature search as barriers with present solutions or relevant counterarguments in each case. It appears that the results of the questionnaire are in line with the hypothesis that these barriers would not be stressed as much as the other barriers.

Linking the findings from the literature review with the responses from questionnaire, some broad initiatives can be underlined as a way to address the most pressing barriers as identified by this group of austere providers. The first is embracing the idea that using POCUS is an extension of the physical exam.[2] Kornelsen et al. presents the concept as follows:

> "For most participants in this study, there was an overall appreciation of PoCUS as a clinical tool that is used to answer specific 'yes-or-no' questions rather than a diagnostic test. When an unexpected finding did arise, participants noted the importance of a radiological consult. This was congruent with others who noted that a key attribute to rural PoCUS use was 'being honest about your limitations.'" [63(p6)]

Stressing this mindset when utilizing the technology could help rectify a key misunderstanding around handheld ultrasound, especially in places where certain specialties such as radiology or obstetrics claim a monopoly over the use of the technology.[60] This mindset could also assist in lowering the barrier of entry for providers who struggle with the sentiment that they are unable to maintain skills to a superior level of care. Kornelsen et al. also described participants finding solutions amongst themselves for the lack of quality-control: "participants developed informal networks and peer support systems to assess the quality of their work and created processes such as parallel studies." [63(p8)] This gives clinicians a valuable solution to combat the feeling that skills are difficult to obtain or maintain via the traditional channels of education. Creating an informal network of experienced providers to mentor those who are interested could help address this educational gap.

Financial barriers are mentioned in nearly every piece of literature on the topic while also being identified as one of the top barriers to further implementation amongst our study sample. Specifically the Australian and Canadian studies admit increased participation and enthusiasm amongst participants due to equipment being provided to them free of charge, while also outlining systemic programs in place that encourage further training.[58,61,63] This provides an interesting window into future opportunities to make the technology more available in areas of need. It stresses, however, the need for government or organizational involvement in order to make the cost-barrier more surmountable for the individual provider.

The limitations of this investigation are best elucidated by looking at the overview of participants. Most obviously, the sample size is small contributing to the relatively large error calculations in the results. Despite the small sample size, we were able to show some significant agreement and disagreement in this relatively specific study population of medical professionals. Another bias that is immediately apparent is that nearly all participants have a workplace in a highly developed healthcare system, something that will clearly bias some of the answers in this questionnaire. A final remark regarding the limitations is that nearly half of the participants do not have experience using POCUS, something that could potentially reduce the overall value of their opinion regarding the barriers to further use of this technology in a highly specific scenario.

4.4. Conclusion

Synthesizing findings from a literature review, questionnaire, and semi-structured interviews, this project thesis explores the multifaceted barriers that impede the integration of an innovative technology into healthcare practices in resource-limited areas. The identified hurdles encompass various dimensions, from technological and financial constraints to training and administrative challenges, among others, each demanding tailored approaches for successful implementation. Recognizing the significance of these barriers is pivotal for the formulation of effective strategies aimed at introducing handheld ultrasound as a pioneering diagnostic tool in regions where access to definitive diagnostic modalities is limited.

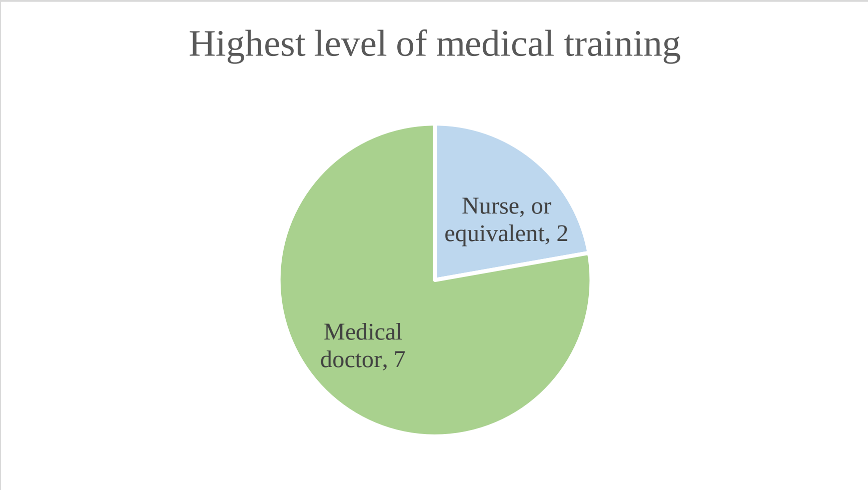
The overall intention of this project thesis is to contribute a perspective to ongoing discussions on healthcare accessibility in resource-limited regions. By illuminating specific challenges associated with the adoption of handheld ultrasound in austere environments, the intention is not only to underscore the importance of overcoming these barriers but also to provide practical suggestions and recommendations that can guide future efforts in the successful implementation of handheld ultrasound technology.

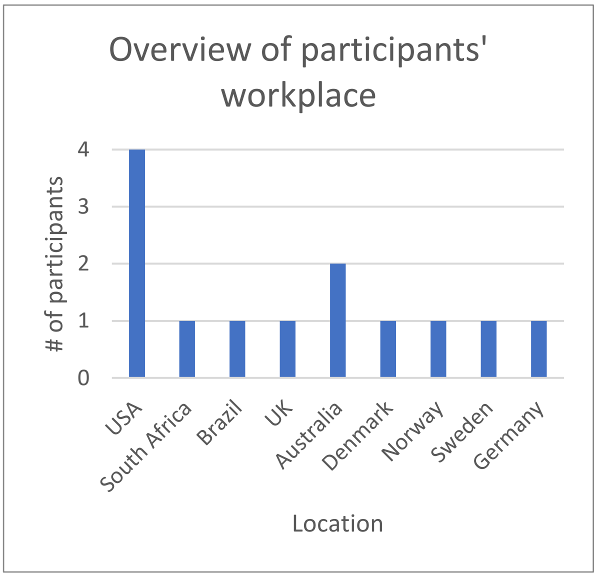
Moving forward, providers in relevant environments can take several steps to improve implementation of this technology. First, any attempt to use handheld ultrasound in a unique clinical application or unique austere environment should be thoroughly documented and ideally published. Second, clinicians should stay abreast of updates in the field, constantly evaluating whether the technology could benefit their own patient population. In such cases, these clinicians may be more inclined to make the necessary investments to overcome the most pressing barriers. Finally, fostering a continued dialogue around topics introduced in this questionnaire and follow-up interview may assist in identifying common solutions.

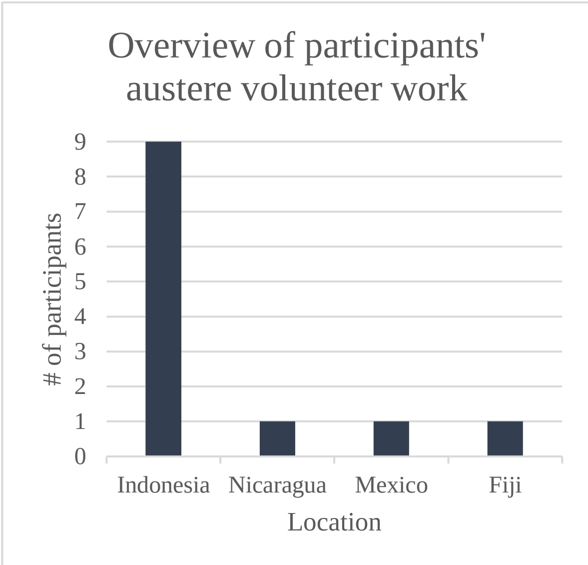
As actors in the field of global health strive for inclusivity and equity, the potential impact of handheld ultrasound in resource-limited areas cannot be ignored. Ideally, a nuanced understanding of the barriers will foster dialogue, drive future research endeavors, and ultimately contribute to the realization of effective and sustainable healthcare solutions for individuals residing in rural, remote, and austere environments.

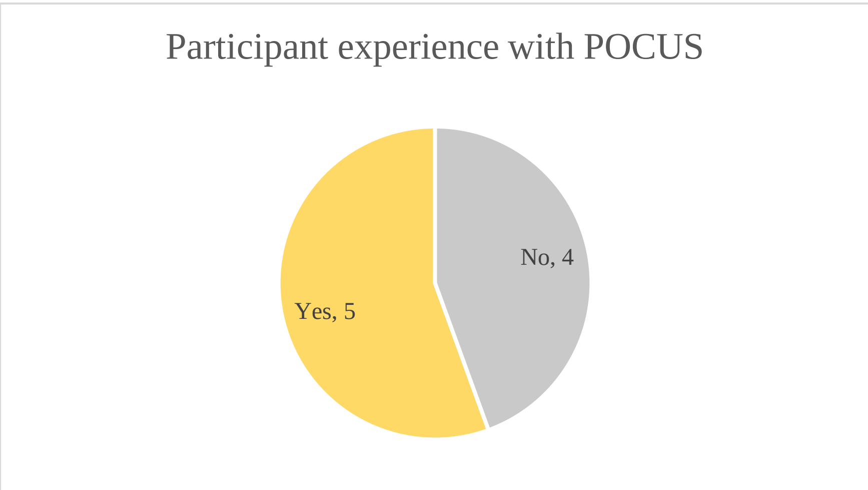
5. Appendices

Appendix I: Figures

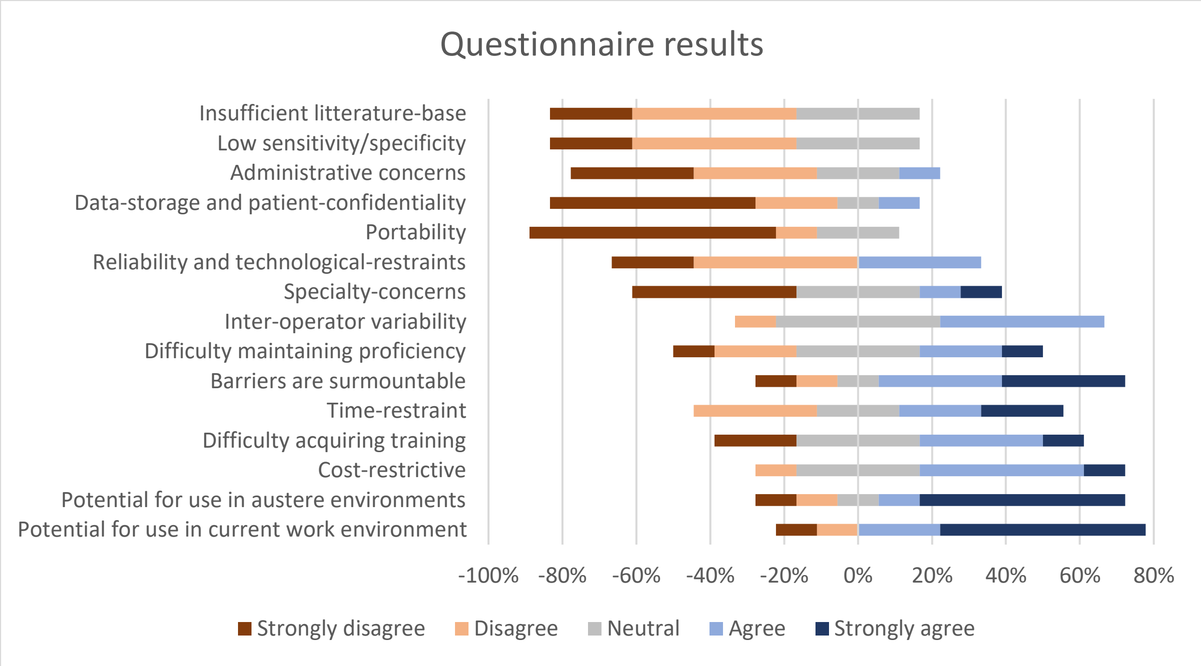








<u>Figures 1-4</u>: Overview of participants (n = 9)



Figures 5: Overview of the opinions on specific barriers to use held by providers with experience working in austere environments (n=9)

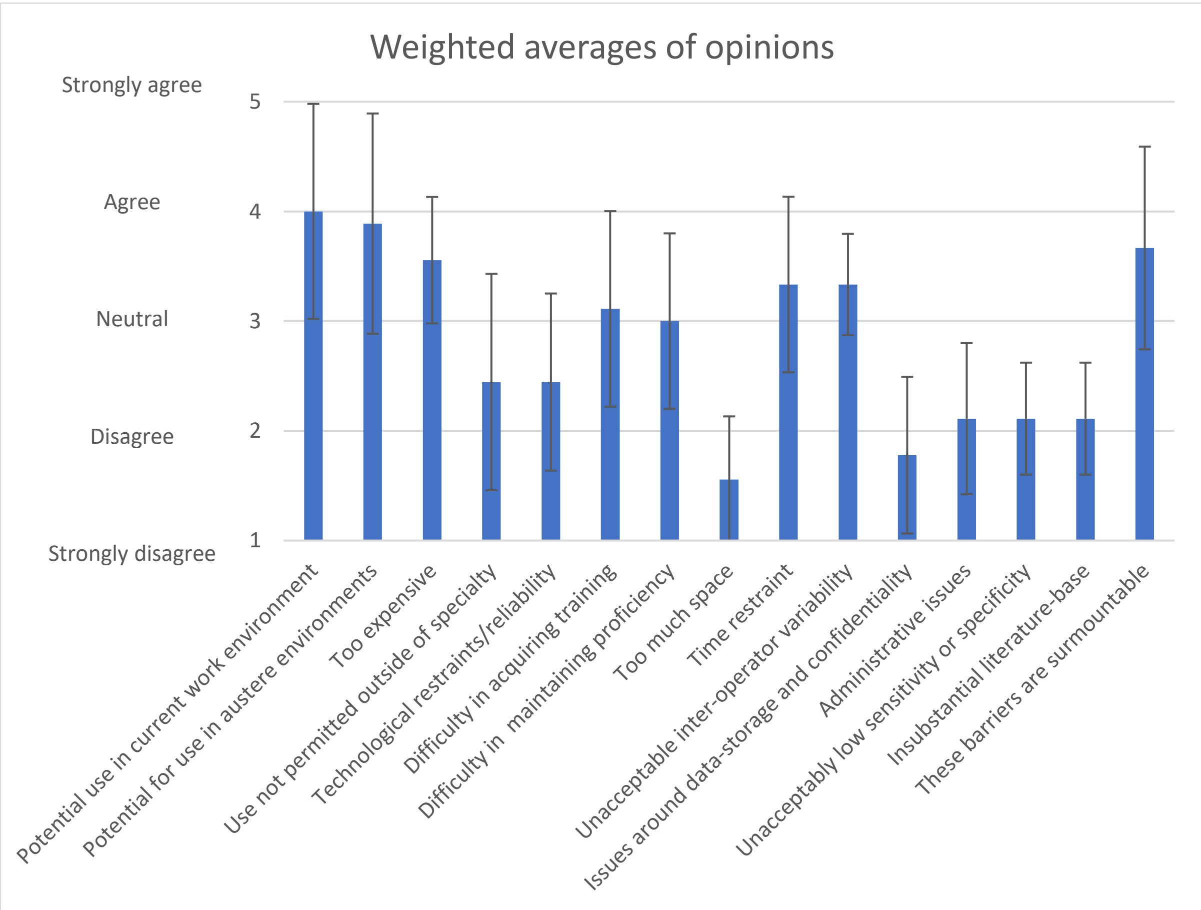


Figure 6: Overview of responses to the questionnaire using weighted averages and standard error to assess the significance of each opinion.

Appendix II: Content of the questionnaire

Usage of handheld point-of-care ultrasound (POCUS) in remote, rural and austere environments

An exploratory study of the opinions of medical personnel and barriers to use of this developing technology in resource-limited environments.

Created by Nicholas Scott Frazier, medical student at the University of Oslo (UiO).

Sign in to Google to save your progress. Learn more

What is your highest level of medical training?

- ○ Medical doctor
- ○ Nurse, or equivalent
- ○ Paramedic or other emergency first-responder
- ○ Other healthcare provider

Have you completed a specialization? If so, what?

Your answer

What country, or countries, do you practice medicine in? Please include career and volunteer-work, if relevant.

Your answer

What type(s) of location(s) do you work in?

- ☐ Metropolitan
- ☐ Rural
- ☐ Remote, austere or resource-limited
- ☐ Other:

Do you have experience using handheld or portable point-of care ultrasound (POCUS)?

- ○ Yes
- ○ No

Please provide your option on the following statements:
1 - strongly disagree
2 - disagree
3 - neutral
4 - agree
5 - strongly agree

There is potential to utilize handheld-ultrasound in my work environment?

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

There is potential to utilize handheld-ultrasound in austere, remote, rural or resource-limited environments?

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

The following have been identified in the literature as barriers to more widespread use of ultrasound in rural, remote, austere or resource-limited environments
Please provide your opinion on a scale from 1-5.

Too expensive to purchase or maintain

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Use not permitted outside of a certain specialty

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Technological restraints that make it not reliable or durable enough for an austere environment

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Difficulty in acquiring training

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Difficulty in maintaining proficiency

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Takes up too much space

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Not enough time for creating protocols, training other providers or providing/receiving oversight

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Unacceptable variation in results or findings between operators

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Issues around data-storage and patient-confidentiality

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Administrative issues, such as patient-billing, device ownership or protection of devices (against f.ex. theft)

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Unacceptably low sensitivity or specificity in relevant diagnostic studies

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

Insubstantial literature-base to support widespread implementation in resource-limited environments

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

These barriers are surmountable, given time and resources devoted to further implementation.

Strongly disagree 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Strongly agree

The study includes a follow-up semi-structured interview with a small selection of questionnaire participants. If you would not mind being contacted for a 15-minute follow-up, please fill out you email address here:

(Note: if you would like to keep these answers anonymous, you can instead contact me at: n.s.frazier@studmed.uio.no)

Appendix III: Specific studies excluded in the literature search

97 results using search function, 33 results post-2021. 2 studies met inclusion criteria that were found external to PubMed search via manual search of the references of included studies.

25 Excluded:

- Study type:
    - Stroffolini et al. 2023
    - Richards et al. 2023
    - Straily et al. 2021
    - Sibbald et al. 2021
- Training-focus and focus on protocol development
    - Wachira J et al. 2023
    - Kim et al. 2023
    - Wanjiku et al. 2023
    - Son et al. 2023
    - Coombs et al. 2023
    - Acheampong et al. 2022
    - Lipsitz et al. 2022
    - Dewar et al. 2022
    - Kameda et al. 2022
- Operator with limited medical education
    - Chen et al. 2022
    - Kaneko et al. 2022
    - Francis et al. 2021
    - Voleti et al. 2021
- In-hospital (high-resource)
    - Ekambaram et al. 2023
    - Lo H et al. 2022
    - Hwang et al. 2022 (+ US not focus)
    - Kaneko T et al. 2023
    - Zhou et al. 2023
- Technological-focus
    - Chen et al. 2023
- US used but not focus of study
    - Cavanna et al. 2021
    - Dávila-Román et al. 2021

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