Feasibility of Imaging Using Portable Ultrasound Device (USD) and Mobile Phone for Point-of-care Diagnosis in Ophthalmic Patients

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ABSTRACT

Medical imaging is important in clinical diagnosis and the individualized treatment of eye diseases. Ultrasound imaging is one of the most prominent technologies for evaluating the orientation, anomalies, and anatomical features of the eye and orbit. However, the interpretation of the data obtained from such studies is best left to expert physicians and technicians who are trained and well-versed in analyzing such images. This technology can provide high-resolution information regarding anatomic and functional changes. In recent years, imaging techniques have developed rapidly, along with therapeutic advances. However, with the increasing sophistication of imaging technology, comprehension and management of eye disease has become more complex due to the large numbers of images and findings that can be recorded for individual patients, as well as the hypotheses supported by these data. Thus, each patient has become a "big data" challenge. Conventional diagnostic methods depend greatly on physicians' professional experience and knowledge, which can lead to a high rate of misdiagnosis and wastage of medical data. The new era of clinical diagnostics and therapeutics urgently requires intelligent tools to manage medical data safely and efficiently.

Keywords: Point-of-care ultrasound (POCUS), Ophthalmic imaging, Portable ultrasound, Mobile phone diagnosis, Teleophthalmology

INTRODUCTION

Using portable ultrasound devices in conjunction with mobile phones for point-of-care diagnosis in ophthalmic patients could indeed expedite healthcare delivery, especially where access to specialized healthcare facilities may be limited. Here's an assessment of the feasibility:

1. Cost-effectiveness: Portable ultrasound devices are becoming increasingly affordable, and many models are designed for point-of-care use. Since most healthcare workers already possess smartphones, combining the two could be cost-effective compared to traditional ophthalmic imaging equipment. This approach also saves the patient and their relatives time and money travelling to areas with conventional imaging equipment.
2. Accessibility: Portable ultrasound devices are lightweight, easily transportable, and don't require a dedicated power source, which is a major advantage in areas with limited infrastructure. Given that mobile phones are ubiquitous, even in remote areas, this technology is readily accessible.
3. Ease of use: Many portable ultrasound devices are designed to be user-friendly, requiring minimal training for healthcare workers to operate. Mobile phone applications can further simplify the process by

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providing intuitive interfaces for image acquisition and analysis.

4. Remote consultation: By capturing images using a mobile phone, healthcare workers can transmit them to specialists for remote consultation. This enables timely diagnosis and management recommendations without the need for patients to travel long distances.
5. Diagnostic capabilities: While portable ultrasound devices may not offer the same level of detail as specialized ophthalmic imaging equipment like optical coherence tomography (OCT), they can still provide valuable information for diagnosing conditions such as cataracts, retinal detachments, retained intraocular foreign bodies, and ocular trauma. For certain conditions, such as assessing optic nerve head cupping in glaucoma, ultrasound may even be preferred over other imaging modalities.
6. Challenges: There are challenges to consider, such as ensuring the reliability and accuracy of imaging performed by individuals with varying levels of training. Additionally, internet connectivity may be unreliable in remote areas, limiting the ability to transmit images for remote consultation. Power outages, experienced frequently in some developing countries like India and Nigeria, are also a challenge.
7. Healthcare delivery: The point-of-care diagnosis with portable ultrasound and smartphone for ocular sonography will improve overall healthcare delivery and create awareness of the alternative, compared to existing but inadequate diagnostic centers. Presently, very few people (in a study conducted in Nigeria) are aware of telemedicine, but many are willing to pay for it when it becomes available. Teleconsultation and telementoring are already being practiced by many healthcare providers in Nigeria. Point -of -focus ultrasonography is an innovation that will greatly enhance ophthalmic practice in the country.

Overall, while there are challenges to address, the use of portable ultrasound devices in conjunction with mobile phones holds promise for expediting healthcare delivery and improving access to ophthalmic care (especially in developing countries where ultrasound services may not be readily available). Collaboration between healthcare providers, technology developers, and policymakers will be essential to maximize the potential of this approach.

In many regions across the globe, access to specialized healthcare services remains a challenge, particularly in remote areas. This limitation is especially pronounced in ophthalmic care, where timely diagnosis and management are crucial for preventing irreversible vision loss. However, amidst these challenges, technological innovations offer a beacon of hope in the form of portable ultrasound devices coupled with ubiquitous mobile phones. By harnessing the power of these technologies, healthcare delivery can be expedited, bridging the gap between patients and essential ophthalmic services. Portable ultrasound devices have emerged as versatile tools for point-of-care diagnosis, offering convenience, affordability, and portability. Coupled with the widespread availability of mobile phones, this combination presents a unique opportunity to revolutionize ophthalmic care delivery. This paper explores the feasibility and potential impact of leveraging portable ultrasound devices in conjunction with mobile phones for point-of-care diagnosis in ophthalmic patients, with a specific focus on expediting healthcare delivery.

The Rural Setting

In the Indian rural context, for example, the integration of portable ultrasound devices with mobile phones has particular relevance for preventing avoidable blindness. Large segments of the population in remote villages present late with advanced ocular disease, often due to lack of nearby specialist services, long travel distances, and the financial burden associated with seeking care at tertiary centers. Many of these conditions, including advanced cataract, vitreous hemorrhage, retinal detachment, or occult ocular trauma, can lead to irreversible visual impairment if not detected and treated promptly. A point-of-care ophthalmic ultrasound device, deployed at primary health centers, vision centers, or during community outreach camps, offers a practical means to identify sight-threatening pathology early and to intervene before blindness becomes permanent. This is particularly important in India, where the social and economic consequences of preventable blindness extend beyond the individual to entire families who depend on a single wage earner.

Emotional and Community Impact

The emotional impact of preventable blindness in rural communities underscores the urgency of timely diagnosis. Patients who lose vision in one or both eyes due to conditions that could have been detected earlier frequently experience profound psychological distress, loss of independence, and reduced quality of life. Point-

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of-care ultrasonography provides an opportunity to change this narrative by enabling rapid, bedside assessment of the eye in patients who may not have immediate access to an ophthalmologist. When a rural community health worker detects a treatable condition and initiates a prompt referral, it not only preserves vision but also builds trust in the health system and reinforces the value of early presentation.

Primary Aim of the Endeavor

The primary aim of this endeavor is to address the pressing need for timely and accurate diagnosis of ophthalmic conditions, which often require specialized imaging modalities such as optical coherence tomography (OCT) or ultrasound biomicroscope (UBM). However, these modalities are typically confined to tertiary healthcare facilities, leaving many patients in underserved regions without access to essential diagnostic services. By integrating portable ultrasound devices with mobile phones, healthcare providers can bring diagnostic capabilities directly to the point of care, whether it be a rural clinic, a community health center, or even a patient's home. This paradigm shift not only reduces the burden on centralized healthcare facilities but also empowers frontline healthcare workers to make informed clinical decisions in real-time.

Furthermore, the synergy between portable ultrasound devices and mobile phones facilitates remote consultation and collaboration with ophthalmic specialists. Through telemedicine platforms, images captured on a mobile phone can be securely transmitted to experts for interpretation, enabling timely diagnosis and management recommendations. This remote support system is particularly valuable in regions where access to specialized care is limited, allowing patients to receive expert guidance without the need for costly and time-consuming travel.

Figure 1. (A) Traumatic cataract (B) Intraocular Foreign Body (C) Plexiform/Orbital Neurofibromatosis (D) Ocular Trauma (E) Retinoblastoma.

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METHODOLOGY

There are different ways of performing ultrasound-based diagnostic procedures. Depending on the application, the sonographer acquires either a single image or an image series. The second approach is better when a further automated image processing step is introduced. Simultaneous analysis of multiple data sets provides reliable results, less prone to artifacts and outliers. At the same time, the analysis of the entire recording might be disturbed by strongly distorted data or artifacts influencing the geometry of visualized structures, appearing in part of the frames. Consequently, it leads to misclassification, false-positive detections, and finally, inaccurate results of measurements. Therefore, the overall goal of this study was to develop and evaluate the classification framework, which enables robust and fast POCUS series analysis.

Ocular ultrasonography in the ambulatory and critical care setting has become an invaluable diagnostic tool for patients presenting with traumatic or atraumatic vision and ocular complaints. Sonographic bedside evaluation is intuitive and easy to perform and can accurately diagnose a variety of pathologies. These include detachment or hemorrhage of the retina or vitreous, lens dislocation, retrobulbar hematoma or air, as well as ocular foreign bodies, infections, tumors, and increased optic nerve sheath diameter that can be assessed in the setting of suspected increased intracranial pressure. The ocular anatomy is easy to visualize with sonography, as the eye is a superficial structure filled with fluid. Over the last two decades, several scientific publications have documented that ocular ultrasound in emergent or critical care settings is an accurate diagnostic tool and expands and improves emergency diagnosis and management.

There is an abundance of ultrasound datasets for various use-cases, which can be used to generate DNN-based models for classification and segmentation. For instance, the breast ultrasound image dataset presented by Al-Dhabyani et al. (Al-Dhabyani et al., 2020), which is composed of normal, benign, and malignant images that can be used to train a model to act as a classifier. Similarly, the POCUS dataset, presented by Born et al. (Born et al., 2020), and the COVIDX-US dataset, by Ebadi et al. (Ebadi et al., 2021), are openly accessible for building DNN-based clinical assistants that can aid in the analytics and diagnosis of COVID-19. Leclerc et al. (Leclerc et al., 2019) presented a cardiac ultrasound electrocardiography dataset containing image sequences with two and four-chamber views of the heart of 500 patients. Likewise, there are a wide number of ultrasound datasets for diagnosing and analyzing several internal body organs.

Recent surveys of machine learning (ML) for medical imaging, such as [1], [2], [3], [4], primarily focus on computerized tomography (CT), magnetic resonance imaging (MRI), and microscopy. In this review, we focus on the use of ML in USD. The objective of this paper is to review how recent advances in ML have helped accelerate ultrasound image analysis adoption by modeling complicated multidimensional data relationships that answer diagnosis and disease severity classification questions. We have two goals: (1) to highlight contributions that utilize ML advances to solve current challenges in medical USD, (2) to discuss future opportunities that will utilize ML techniques to further improve clinical workflow and USD-based disease diagnosis and characterization.

The effort and domain expertise involved in handcrafting features have led researchers to seek algorithms that can learn features automatically from data. Deep learning (DL) is a particularly powerful tool for extracting nonlinear features from data. This is particularly promising in USD where predictable acoustic patterns are typically neither obvious nor easily hand-engineered. The figure below illustrates high-level differences between conventional ML and DL. The fast adoption of DL has been enabled by faster algorithms, more capable Graphics Processing Unit (GPU)-based computing, and large data sets.

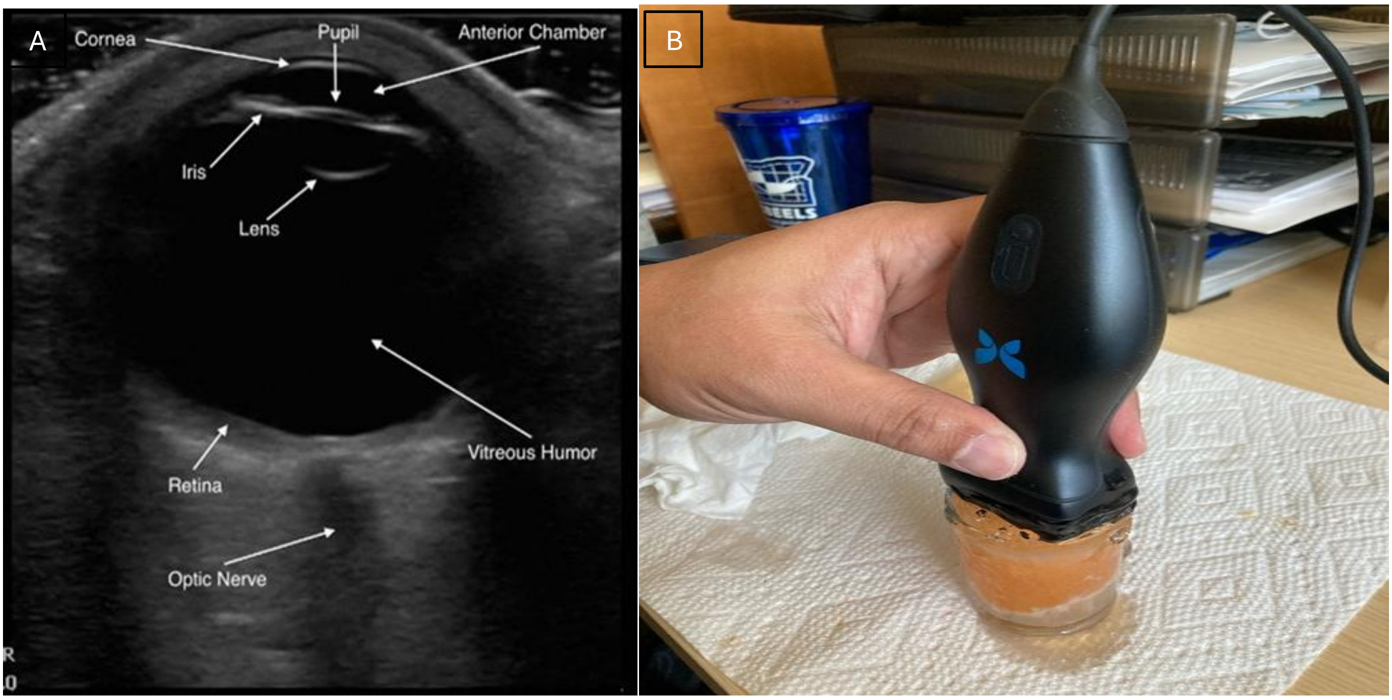
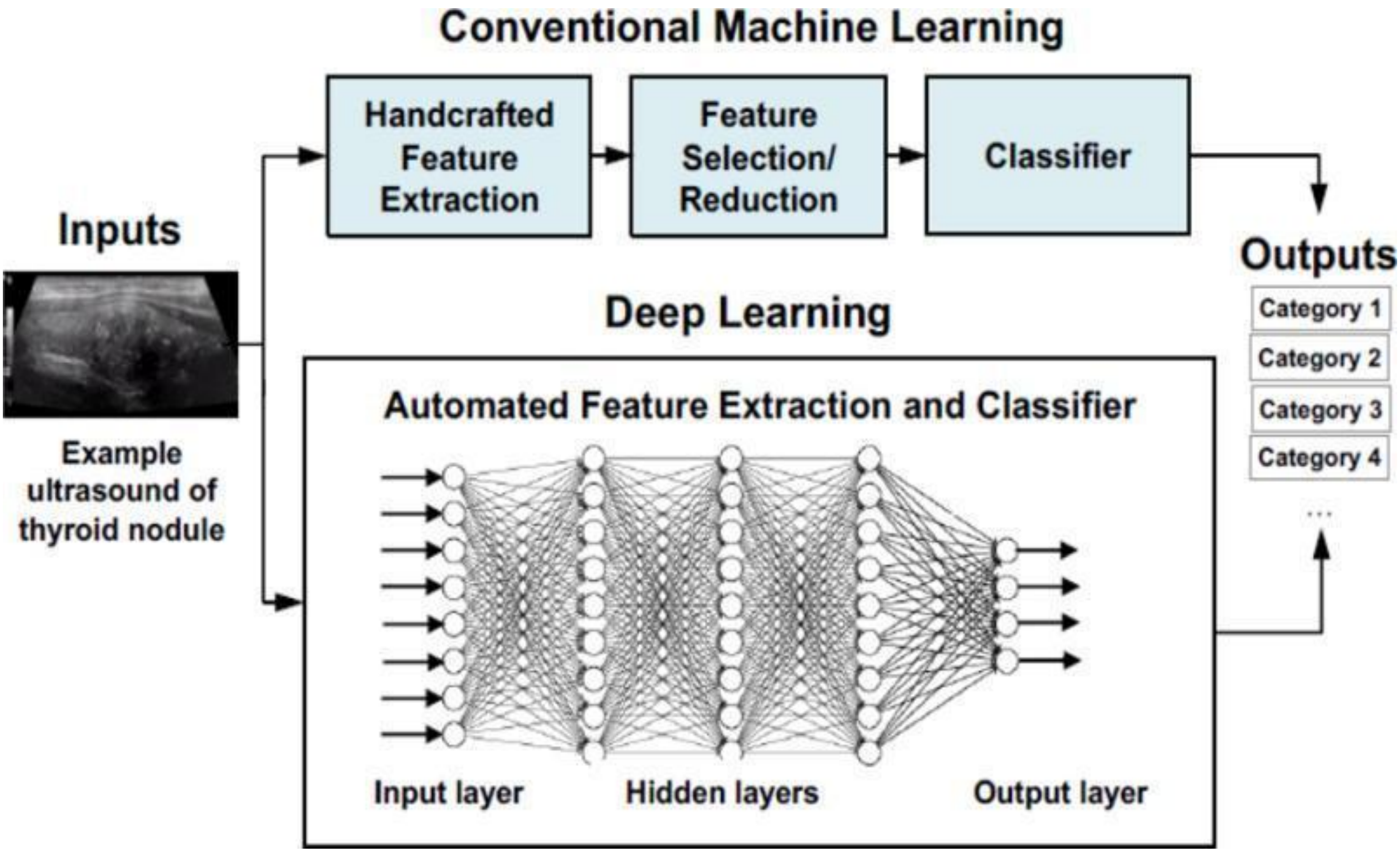


Figure 2. (A) Ultrasound of normal eye using B-Scan Mode (B) Ultrasound apparatus of phantom eye using POCUS



Standard operating procedure for orbital ultrasonography:

1) Complete the consent and authorization form
2) Clean and prepare the site of interest and the ultrasound probe
3) Apply sterile coupling agents to the ultrasound probe headpiece
4) Connect the probe to the mobile device and launch the app

5) Select the appropriate preset to start scanning

a. Horizontal linear scan (medial orientation) - adjust depth and ΔTGC

b. Vertical linear scan (superior orientation) - adjust depth and ΔTGC

c. Lateral vertical oblique scan (Ossoinig technique + Doppler) - optic nerve assessment

d. Horizontal linear (Lacrimal gland) scan - volumetric and ΔTGC

6) 3D scan/Cine recording of orbit

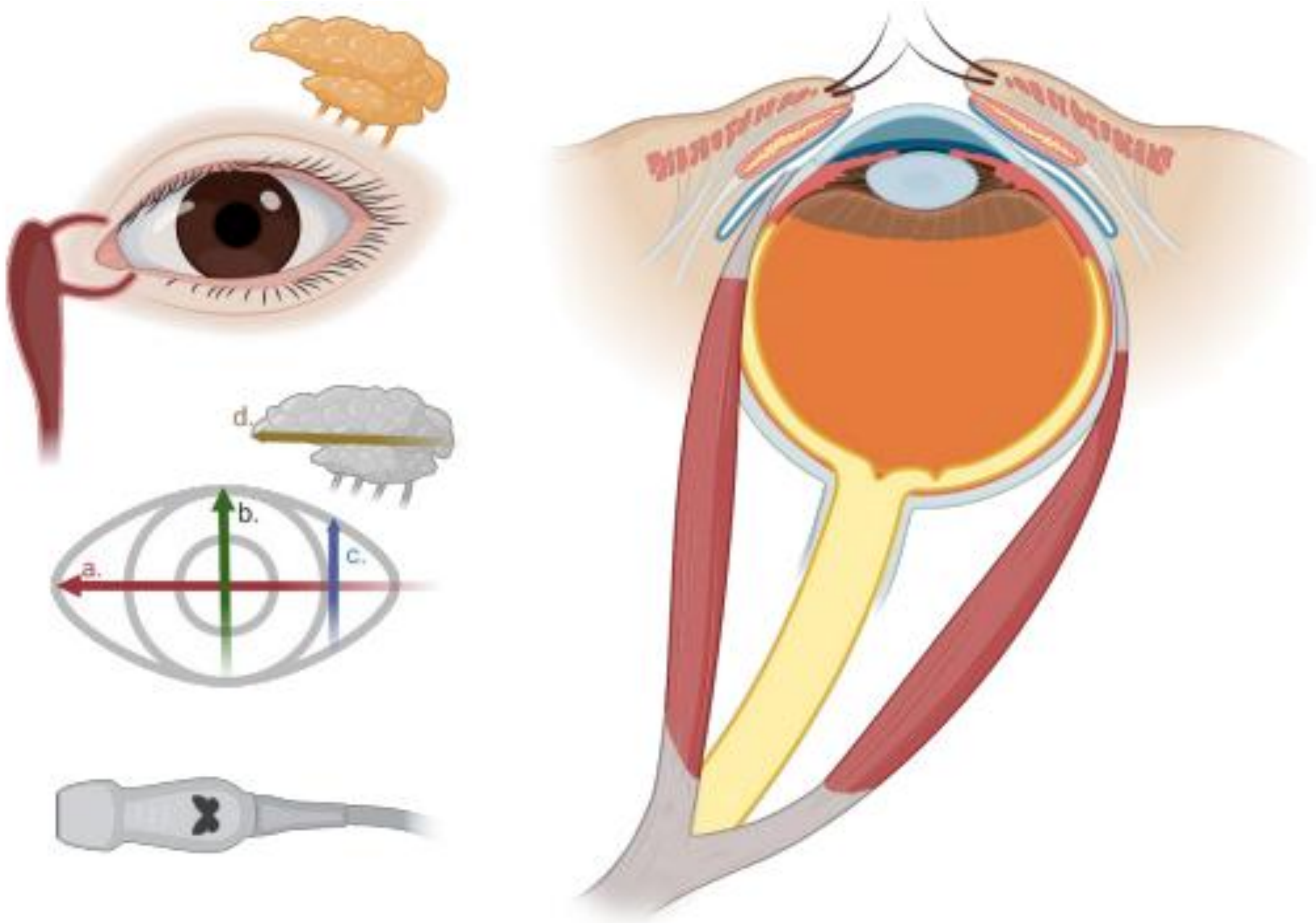


Figure 3: Orbital ultrasonography instructional diagram (Created with BioRender.com) (1).

DISCUSSION

AI Integration and Improved Access

In austere environments, such as remote or under-resourced regions, accessing specialized healthcare services, particularly for ophthalmic conditions, presents significant challenges. Timely diagnosis of ophthalmic disorders is essential for preventing irreversible vision loss, yet traditional diagnostic tools may be scarce or inaccessible in these settings. However, integrating artificial intelligence (AI) with ultrasound technology offers a promising solution to enhance early detection and diagnosis. This paper explores the potential of AI-assisted ultrasound in improving the detection of ophthalmic disorders in austere environments, thereby facilitating timely interventions and mitigating the burden of vision impairment.

Ophthalmic disorders encompass a wide range of conditions, including cataracts, glaucoma, diabetic retinopathy, and retinal detachments, among others. Early detection is critical for initiating appropriate treatment and preventing disease progression. However, in austere environments where access to specialized equipment and trained healthcare professionals is limited, patients often face delays in diagnosis and treatment, leading to adverse outcomes.

Ultrasound imaging has emerged as a valuable tool for ophthalmic diagnosis, offering portability, affordability, and versatility. In austere environments, where traditional imaging modalities may be unavailable, handheld ultrasound devices provide a feasible solution for visualizing ocular structures and detecting abnormalities. By leveraging AI algorithms trained on large datasets of ophthalmic ultrasound images, these devices can enhance diagnostic accuracy and empower frontline healthcare providers to identify ophthalmic disorders with greater confidence.

The integration of AI with ultrasound technology enables real-time analysis of ultrasound images, allowing for automated detection of pathological features indicative of various ophthalmic conditions. AI algorithms can distinguish between normal and abnormal findings, flagging suspicious findings for further evaluation by healthcare providers. This augmentation of diagnostic capabilities is particularly valuable in austere environments where access to ophthalmologists or specialized training is limited, enabling non-specialist healthcare workers to make informed clinical decisions.

Humanitarian and Operational Impact

The deployment of smartphone-based portable ultrasonography in rural demographics addresses the critical humanitarian and economic crisis of preventable blindness. In regions such as rural India, where a significant portion of the population relies on agricultural or daily wage labor, the irreversible loss of vision in a family member creates a catastrophic ripple effect on household financial stability. By relocating diagnostic capacity from tertiary centers to the village level, this technology knocks down the distance barrier that frequently leads to delayed presentation. The ability to detect treatable pathologies like vitreous hemorrhage or mature cataracts at the primary care level transforms a potential lifetime of disability into a manageable medical event, thereby preserving both individual independence and community economic resilience.

Furthermore, the operational value of this technology lies in its ability to refine emergency triage protocols within tiered healthcare systems. In the presence of opaque media, where traditional ophthalmoscopy fails, portable ultrasound provides immediate visualization of the posterior segment to rule out sight-threatening emergencies such as retinal detachment or intraocular foreign bodies. This capability ensures that patients requiring urgent surgical intervention are prioritized for immediate transfer, while those with non-urgent conditions can be managed locally or referred routinely. By arranging patient care based on need, the available specialist expertise is maximized. This approach guarantees that urgent eye conditions are treated within the critical time frame, significantly reducing the chances of irreversible blindness.

Furthermore, AI-assisted ultrasound facilitates remote consultation and collaboration with ophthalmic experts. Images acquired in austere environments can be transmitted securely to centralized facilities or specialist centers, where trained professionals can provide interpretation and guidance. This telemedicine approach enables timely diagnosis and management recommendations, bridging the gap between underserved communities and specialized care providers.

In conclusion, the convergence of portable ultrasound devices and mobile phones holds immense potential to expedite healthcare delivery and improve access to ophthalmic diagnosis. By embracing these technologies, stakeholders in the healthcare ecosystem can pave the way for a more inclusive and efficient healthcare system, ultimately enhancing the quality of life for ophthalmic patients across the country.

The integration of AI-assisted ultrasound technology holds tremendous promise for improving the early diagnosis of ophthalmic disorders in austere environments. By enhancing the diagnostic capabilities of frontline healthcare providers and facilitating remote collaboration with specialists, AI-assisted ultrasound has the potential to revolutionize ophthalmic care delivery, ultimately reducing the burden of vision impairment and improving patient outcomes in challenging settings.

Challenge

Ultrasound images of the eye are challenging to use with Machine Learning (ML) because such images are often fuzzy and lack prominent, distinct features. ML requires thousands, or even tens of thousands, of images for robust training purposes. The primary challenge is creating such a large collection of high-quality ultrasound images without involving thousands of patients, which currently makes the task of building a purely automated diagnostic system difficult.

However, should our efforts prove unsuccessful in creating fully automated diagnostic software, we can pivot to developing a semi-automated interactive system. In this setup, eye specialists would actively participate, contributing their domain knowledge to guide the process and make the system more effective.

CONCLUSIONS

AI-powered ocular Ultrasound for Early Detection of Eye Disorders is a promising research direction that can potentially improve the accuracy, efficiency, and accessibility of ocular ultrasound diagnosis. It can also help prevent or delay the progression of eye disorders and preserve the visual function of the patients. However, there are also some challenges and limitations that need to be addressed, such as the availability and quality of ocular ultrasound data, the generalization and validation of AI models, the ethical and legal implications of AI applications, and the integration and acceptance of AI systems in clinical practice.

Declaration of Helsinki

This review adheres to the ethical principles outlined in the Declaration of Helsinki as amended in 2013. (https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/).

Conflict of interest: The corresponding author(H.KH) is a Research scholar and visiting professor, Division of Oculofacial Plastic, Orbital, and Reconstructive Surgery, Oregon Health and Science University, Portland, Oregon, and *Department of Mechanical Engineering/Portland State University*.

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