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Evaluation of Optic Nerve Sheath Diameter Measurements in Eye Phantom Imaging using POCUS and AI

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ABSTRACT

The aim of this review is to provide a wide overview of optic nerve ultrasound normal values assessment using eye phantom imaging techniques using POCUS. We examine the suitability of commercially available, low-cost, portable ultrasound devices that can be combined with artificial intelligence algorithms to reduce the training required for and cost of in-field optic nerve sheath diameter measurement.

Several disorders can affect the optic nerve and their differential diagnosis can be challenging, requiring expensive or uncomfortable tests. Elucidation of its underlying disease and follow up may require expensive or uncomfortable tests or even invasive procedures like lumbar puncture. Ultrasound has been widely used for this purpose, but it requires knowledge and skill to give reliable results.

Methods: Transorbital sonographic measurement of optic nerve sheath diameter (ONSD) was measured by pointof-care ultrasound machines on phantom ONS model. Measurements were analyzed for mean error and variance and tested for significance using regression analyses. We developed a low cost, easily made phantom model that may assist with training and improve the quality of sonographic measurements of the ONSD. This study aims to: (1) provide a step-by-step description of producing a sonographic phantom of the posterior chamber of the eye; and (2) validate the model as a realistic educational tool utilizing in vivo and phantom ONS images obtained by ultrasound.

Outcome: Accurate ONSD measurement is possible utilizing POCUS. Measurement of the optic nerve sheath diameter (ONSD) via ultrasonography has been proposed as a non-invasive metric of intracranial pressure that may be employed during in-field patient triage. However, first responders are not typically trained to conduct sonographic exams and/or do not have access to an expensive ultrasound device. Therefore, for successful deployment of ONSD measurement in-field, we believe that first responders must have access to low-cost, portable ultrasound and be assisted by artificial intelligence (AI) systems that can automatically interpret the optic nerve sheath ultrasound scan.

Keywords

Ultrasound computer tomographs, Ultrasound waves, X-ray, Sound pressure.

Introduction

Ultrasound computer tomographs (USCT) use ultrasound waves for creating images. In the first measurement step a defined ultrasound wave is typically generated with Piezoelectric ultrasound transducers, transmitted in direction of the measurement object and received with another or the same ultrasound transducers. While traversing and interacting with the object the ultrasound wave is altered by the object and transmits information about the object. After being recorded the information from the modulated waves can be extracted and used to create an image of the object after image acquisition. Unlike X-ray or other physical properties which typically provide only one type of information, ultrasound provides multiple modes of information about the object for imaging: the attenuation the wave's sound pressure experiences reflect the object's attenuation coefficient, the time-of-flight of the wave gives speed of sound information, and the wave scatter indicates the echogenicity of the object (e.g. refraction index, surface morphology, etc.). Unlike conventional ultrasound sonography, which uses phased array technology for beam formation, most USCT systems utilize unfocused spherical waves for imaging. Most USCT systems aim for 3D-imaging, either by synthesizing ("stacking") 2D images or by full 3D aperture setups. Another study goal is quantitative imaging instead of only qualitative imaging [1].

3D ultrasonography in the ambulatory and critical care settings has become an invaluable diagnostic tool for patients presenting with traumatic or atraumatic vision loss and ocular complaints. For properly trained ophthalmologists, sonographic bedside evaluation is intuitive, easy to perform, and can accurately diagnose a variety of pathologies. Also, they are fast in data acquisition as they do not require time-intensive mechanical manipulation of the probe. Detection of pathology includes detachment or hemorrhage of the retina, choroid or vitreous, lens dislocation, or subluxation, globe rupture or scalopetaria retinae, commotio retinae, retrobulbar hematoma, ocular and orbital foreign bodies, infections, cellulitis, inflammation, tumors, orbital compartment syndrome and increased optic nerve sheath diameter that can be assessed in the setting of suspected increased intracranial pressure and many more conditions. The ocular anatomy is easy to visualize with sonography, however, orbital ultrasound remains a challenge. Over the last two decades, many scientific publications have documented that 3D ultrasound in emergent or critical care settings is an accurate diagnostic tool and expands and improves emergency diagnosis and management [2].

Material and Methods TISSUE-MIMICKING PHANTOM

The innovation of this project lies in its multifaceted approach to revolutionizing ocular healthcare through the integration of cutting-edge technologies and methodologies. By developing highfidelity phantom tissue models and simulated ultrasound images that replicate real tissue properties, the project ensures realistic AI training for accurate diagnosis of optic nerve neuropathy and other ocular pathologies. The establishment of a curated ultrasound image database, along with the design and training of a robust deep neural network (DNN) system, further enhances diagnostic capabilities. Additionally, the project's focus on refining DNN models, integrating them into a user-friendly web-based platform, conducting prospective clinical trials, and extending methods to address various ocular conditions demonstrates its forwardthinking and comprehensive approach to advancing ocular healthcare.

The innovation of this project can be listed as:

1. High-Fidelity Phantom Tissue Models: Developing highly



accurate phantom tissue models that closely mimic the acoustic properties of real ocular tissues is innovative. These models offer a controlled and reproducible platform for training AI algorithms, which is crucial for advancing the field of ocular ultrasound imaging.

- 2. Simulated Ultrasound Images: Generating simulated ultrasound images with realistic features adds a new dimension to the training process. By replicating the complexities of real ultrasound scans, researchers can provide AI algorithms with diverse and representative training data, enhancing their ability to detect and diagnose optic nerve neuropathy and other ocular pathologies.
- 3. Integration of AI Technology: Leveraging artificial intelligence (AI) for the analysis of ocular ultrasound images is an innovative approach. By training deep neural networks (DNNs) using the high-fidelity phantom tissue models and simulated ultrasound images, the project aims to develop a robust AI-powered system capable of accurate and rapid diagnosis of optic nerve neuropathy.
- 4. User-Friendly Web-Based Platform: Designing a user-friendly web-based platform for real-time analysis of ocular ultrasound

images is innovative and addresses the need for accessible and efficient diagnostic tools in eye care. Integrating the AIpowered system into this platform enhances its usability and practicality for eye care professionals, particularly in regions lacking sophisticated equipment and facilities.

5. Extension to Other Ocular Pathologies: The project's plan to extend the developed methods to address other ocular pathologies, such as trauma, tumors, and inflammation, demonstrates forward-thinking and a broader impact on ocular healthcare beyond optic nerve neuropathy.

Overall, the innovative combination of high-fidelity phantom tissue models, simulated ultrasound images, AI technology, user-friendly interface, and extension to other ocular pathologies positions this project at the forefront of advancing ocular healthcare through AIenhanced ultrasound technology.

Phantoms are objects designed to mimic the properties of human tissue and are used to study and develop new medical imaging and treatment options. The development of phantoms that accurately and reliably mimic the properties of human tissue is extremely



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important. Phantoms are used in quality assurance and validation of new imaging and treatment techniques. A variety of commercial phantoms for use with ultrasound or MR are available, however we believe that fabricating phantoms with custom shapes and tissue properties is essential to our research process. We have developed a methodology for fabricating gelatin phantoms that successfully mimic many of the acoustic, thermal and mechanical properties of human tissue. These phantoms are relatively simple to make and easily modifiable which allows them to be used for a variety of experiments.

Approach

This project aims to enhance early detection of optic nerve neuropathy (ONN) through AI-powered ocular ultrasound technology. It involves gathering diverse datasets of ocular ultrasound images, exploring various CNN architectures, training, and validating the models, evaluating performance metrics, and deploying the best-performing model into a user-friendly interface for real-time ONN detection in clinical settings. The details are:

• **Data Collection:** Gather diverse datasets comprising ocular ultrasound images, including optic nerve sheath diameter (ONSD) measurements and head anatomy scans. These datasets will be sourced from clinical records, experimental studies, and imaging databases to ensure representation across various ONN conditions and demographics.

- **Model Selection:** Explore different convolutional neural network (CNN) architectures, including fully convolutional network (FCN), SegNet, and U-net, to determine the most suitable model for automated ONSD and head anatomy analysis. These models will undergo rigorous evaluation to assess their performance in accurately detecting ONN-related abnormalities [3-4].
- **Model Training and Validation:** Divide the dataset into training, validation, and test sets to facilitate model training and validation. Train the selected CNN models using the training data and fine-tune their hyperparameters to optimize performance. Validate the trained models using the validation set to ensure robustness and generalizability [3-4].
- **Model Evaluation:** Assess the performance of the trained CNN models using metrics such as accuracy, precision, recall, and F1-score. Additionally, employ cross-validation techniques to further validate the models' effectiveness in detecting ONN-related abnormalities across diverse datasets.
- **Model Deployment:** Implement the best-performing CNN model into a user-friendly tool or interface that can seamlessly integrate into clinical settings for real-time ONN detection. This deployment will enable healthcare professionals to leverage AI-powered ocular ultrasound technology for rapid and early diagnosis of ONN, thereby improving patient outcomes and facilitating timely interventions.



Machine learning architectures: (a) FCN model, (b) SegNet model, and (c) U-net model



Discussion

Pathological conditions affecting the optic nerve can result in optic nerve neuropathy, a term describing a range of disorders, including optic neuritis, glaucomatous optic neuropathy, ischemic optic neuropathy, and compressive neuropathies through trauma or idiopathically. These conditions often lead to vision impairment or blindness, making their early detection and accurate diagnosis a crucial need in the field of ophthalmology. Conventional diagnostic methods for optic nerve neuropathy include clinical evaluation, visual field testing, and imaging techniques such as optical coherence tomography (OCT) and magnetic resonance imaging (MRI). While these methods provide valuable insights, they have limitations that include a lack of real-time assessment, high costs, and limited portability. It is also much more time-consuming, which prolongs the course of diagnoses and management. As a result, there has been growing interest in developing alternative diagnostic approaches, with ultrasound imaging emerging as a promising candidate.

Ultrasound imaging, widely employed in various medical fields, offers several advantages for evaluating optic nerve neuropathy. It provides real-time, dynamic imaging of tissues, is non-invasive, cost-effective, and can be conducted at the bedside. These features make ultrasound an attractive option for detecting optic nerve abnormalities. Phantom tissue models, designed to mimic the acoustic properties of human ocular tissues, are invaluable for preliminary investigations and method development. They provide a controlled and reproducible environment for refining ultrasound techniques and assessing their diagnostic potential. Real tissue, on the other hand, represents the complexity of human anatomy and physiology, acting as a crucial bridge between controlled experimental settings and clinical application.

This scientific paper aims to evaluate the efficacy of ultrasound in detecting optic nerve neuropathy, comparing them in two distinct models: phantom and real tissue. Our investigation employs POCUS ultrasound, meticulously designed phantom tissue models, and real tissue samples obtained from patients with confirmed optic nerve neuropathy.

The primary objectives of this study are image quality, diagnostic accuracy, feasibility and safety. We will assess the clarity, resolution, and contrast of ultrasound images to determine the extent to which optic nerve abnormalities can be visualized in both phantom and real tissue models. Sensitivity and specificity of ultrasound in detecting optic nerve neuropathy will be evaluated, comparing its performance in phantom and real tissue models. A critical examination of the safety profile of ultrasound will be performed, considering any potential risks and patient comfort.

By addressing these key aspects, we hope to evaluate the strengths and limitations of ultrasound in diagnosing optic nerve neuropathy in both phantom and real tissue settings. Furthermore, our findings may lay the groundwork for the development of more advanced ultrasound techniques, potentially enhancing the early detection and management of optic nerve neuropathy. The ultimate goal of this research is to contribute to the growing body of knowledge regarding the application of ultrasound in ophthalmology, with a potential positive impact on patient care.

In this paper, we will present a comprehensive analysis of our findings, discussing their implications for the field of ophthalmology and the potential for integrating ultrasound into the routine diagnostic and management protocols for optic nerve neuropathy. We believe that our research represents a critical step towards advancing the diagnostic tools available to ophthalmologists, ultimately benefiting the patients who rely on timely and accurate diagnosis and treatment.

Transorbital sonographic measurement of optic nerve sheath diameter (ONSD) was made by point-of-care ultrasound machines on phantom ONS models. Measurements were analyzed for mean error and variance and tested for significance using regression analyses. We developed a low-cost, easily made phantom model that may assist with training and improve the quality of sonographic measurements of the ONSD. This study aims to: (1) provide a step-by-step description of producing a sonographic phantom of the posterior chamber of the eye; and (2) validate the model as a realistic educational tool utilizing in vivo and phantom ONS images obtained by ultrasound.

Our research lab focuses on developing advanced tissue-mimicking phantoms for ultrasonic studies. These phantoms serve as crucial tools for evaluating and improving ultrasonic imaging techniques, as well as for training machine learning algorithms for image analysis and disease diagnosis. In this project, we investigated whether tissue-mimicking phantoms could effectively replace real tissue in training neural networks for the evaluation and diagnosis of diseases. We hypothesized that by meticulously replicating the acoustic properties of various biological tissues, tissue-mimicking phantoms could provide a realistic and reliable substitute for real tissue in training neural networks.

We evaluated image quality, diagnostic accuracy, optic nerve sheath diameter, and dimensions of orbit in both phantom and real tissue images. We evaluated the performance of DNN models trained on US data generated using ocular phantom tissue. A convolutional neural network following the Network-in-Network architecture was trained to predict optic nerve sheath diameter, using the absolute error loss function. The training set consisted of 100 images with optic nerve diameters in the normal range and 40 images with optic nerve diameters in the abnormal range.

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The resulting models were then evaluated on real tissue samples not used during training, consisting of 100 normal images and 30 abnormal images [5].

Results

We used 100 normal human eye scans as test subjects and 30 known abnormal phantom scans as training sets. The resulting training loss is 0.049, and the resulting testing loss is 0.15, indicating the model is overfitting the training set of phantom images. We also considered cases where the optic nerve sheath lies outside the normal range of 0.3 - 0.6 cm. On this, the trained model obtains a precision of 0.34, a recall of 0.83, and an F1 score of 0.49. This indicates that even the overfit model provides significant predictive skill in terms of detecting abnormal optic nerve sheath diameters and may have the potential for the assessment of optic nerve head abnormalities in conditions like optic neuropathy [6].

Figure 1 shows the training and validation error versus epoch. Interestingly, even for a very large number of epochs, the validation loss does not appear to diverge greatly from the training loss. This is likely due to the homogeneity of the training and validation sets, in which the images are very similar. We note that a more careful consideration of overfitting may be necessary when larger training and validation sets become available. The final validation MAE is 0.0925, corresponding to a relative error of 3.96%. For comparison, a simple algorithm that always predicts the median diameters of the training set results in a validation error of 8.72%, indicating that our trained network learns nontrivial predictions corresponding to the actual images, even from this small dataset.



Figure 2 shows a scatter plot of the true and predicted diameters for (a) The training dataset and (b) The validation dataset. The figure shows that the network can accurately capture the training data while still generalizing to the validation set. For the validation data, we see that the network overpredicts the smallest horizontal diameters (bottom left points in Figure 2(b)).



This study indicates the potential predictive skill when training DNNs from US images generated using ocular phantom tissue. This has significant implications for revolutionizing medical imaging practices by reducing the reliance on real tissue samples and paving the way for more efficient training of neural networks for medical applications.

Challenge

Ultrasound images of the eye are difficult to use with ML as such images are too fuzzy and lack prominent features. ML requires thousands, even tens of thousands of images for training purposes. The challenge in Phase I is to create such a large collection of US images without involving thousands of patients which makes the task impossible. Our phantom US images while being close to the real eye US images, need further refinement or image processing to match the noise and artifacts present in real eye images. The ingredients and methods of developing phantoms can be varied to find more realistic US images. However, it is well possible that our efforts may not be successful in creating fully automated diagnostic software. If that turns out to be the case, we can develop a semiautomated interactive system in which the eye specialists would participate and help with their knowledge to guide the process to make it more effective.

Conclusions

AI-powered ocular Ultrasound for Early Detection of Optic Nerve Neuropathy 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 optic nerve neuropathy 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 is adhered to the ethical principles outlined in the

Declaration of Helsinki as amended in 2013. (<u>https://www.wma.</u> net/what-we-do/medical-ethics/declaration-of-helsinki/).

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References

- 1. Aspide R, et al. A proposal for a new protocol for sonographic assessment of the optic nerve sheath diameter: the CLOSED protocol. Neurocrit Care. 2020; 32: 327-332.
- Montorfano L, et al. Mean value of B-mode optic nerve sheath diameter as an indicator of increased intracranial pressure: a systematic review and meta-analysis. Ultrasound J. 2021; 13: 35.
- Dong L, He W, Zhang R, et al. Artificial Intelligence for Screening of Multiple Retinal and Optic Nerve Diseases. JAMA Netw Open. 2022; 5: e229960.
- 4. Zhang L, Tang L, Xia M, et al. The application of artificial intelligence in glaucoma diagnosis and prediction. Frontiers in Cell and Developmental Biology. 2023; 11: 1173094.
- Qian X, Xian S, Yifei S, et al. External validation of a deep learning detection system for glaucomatous optic neuropathy: Eye. 2023; 37: 3813-3818.
- Prof Jeffrey L Bennett, Fiona Costello, John J Chen, et al. Optic neuritis and autoimmune optic neuropathies: advances in diagnosis and treatment. OPTIC NEUROPATHIES. 2022; 22: 89-100.

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