Monitoring the Progress of Subconjunctival Hemorrhage through Spectral Reconstruction from RGB Images

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ABSTRACT

Subconjunctival hemorrhage (SCH) is a prevalent ocular condition characterized by the accumulation of blood beneath the conjunctiva, resulting in a visible red patch on the eye's surface. The appearance of SCH and the limited understanding of its progression can cause significant anxiety for patients. To address this issue and enhance ocular health management, we develop a deep learning-enabled monitoring approach that quantitatively tracks the SCH healing process through spectral reconstruction. Our approach comprises two key technical components. Firstly, automatic white balance algorithms are employed to estimate the light source's color temperature and adjust image colors, minimizing the impact of varying lighting conditions. The SCH segmentation achieves an accuracy of 96.2 %, effectively avoiding interference from skin and eyelashes. Secondly, our monitoring approach evaluates SCH color changes, which are crucial for determining the stage of recovery. By learning a complex mapping function, the approach generates 31 hyperspectral bands (400–700 nm) by recovering the lost spectral information from a given RGB image. This process allows for a more detailed spectroscopic assessment of the affected area. The rich spectral signatures obtained from these hyperspectral images enable the classification of SCH into three distinct stages, reflecting the blood reabsorption process. This study is the first to apply deep learning-based spectral reconstruction to SCH determination, enabling evaluation of the recovery process through spectroscopic and quantitative analysis. This approach has the potential to improve daily patient care and promote better eye health control by offering more comprehensive monitoring of SCH progression.

Keywords: Spectral Reconstruction, Subconjunctival Hemorrhage, Disease Progress Monitoring, Precision Eye Healthcare

1. INTRODUCTION

Subconjunctival hemorrhage (SCH) is a common ocular condition characterized by the accumulation of blood beneath the conjunctiva, which is the transparent tissue covering the white part of the eye.[1] This accumulation causes a visible red patch on the eye's surface, commonly presenting as diffusely hyperemic. Although typically painless and self-resolving within one to two weeks, the alarming appearance of SCH and the limited understanding of its progression can cause significant anxiety for patients.[2] Moreover, SCH can also serve as a cautionary indicator for clinical conditions related to systemic diseases including diabetes, hypertension, cardiovascular issues, and bleeding disorders.[3] Current methods for assessing and monitoring SCH primarily rely on subjective clinical examinations, which may not provide a comprehensive understanding of the healing process.[4] Furthermore, the lack of objective parameters to track SCH progression presents challenges for healthcare professionals in accurately monitoring a patient's recovery and offering appropriate guidance. This highlights the need for a more advanced and precise approach to evaluate and manage SCH.

In the eye care field, there is a growing emphasis on intelligent diagnosis and management solutions, driven by technological advancements.[5,6] Hyperspectral imaging (HSI) is an emerging imaging modality in medical applications, particularly valuable for disease diagnosis.[7,8] Hyperspectral images comprise hundreds of contiguous spectral bands, providing rich information about a scene's composition. This wealth of data positions HSI as a promising tool for enhancing the assessment and monitoring of SCH. At the same time, advancements in spectral

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reconstruction algorithms help address the high costs associated with hyperspectral cameras and the complexity of acquisition systems.[9] These developments further strengthen the potential of HSI as an accessible, precise, and effective method for evaluating and managing SCH in clinical settings.

In this work, we have developed a deep learning-enabled monitoring approach to enhance ocular health management by tracking the SCH healing process through spectral reconstruction and quantification. This approach employs transfer learning techniques to acquire a complex mapping function, enabling the creation of 31 hyperspectral bands ranging from 400 to 700 nm by retrieving the lost spectral data from a provided RGB image. This procedure facilitates a more comprehensive spectroscopic evaluation of the affected region. By combining SCH quantitative techniques, this innovative method offers a more accurate, detailed, and objective assessment of the condition. This highlights the potential implications of our approach for improving patient care and promoting better eye health management.

2. METHODS

Two image datasets were used in this work: the External Eye Photo (EEP) dataset collected from the Lo Fong Shiu Po Eye Centre (LFSC) in Hong Kong, and the publicly available Sclera Blood Vessels, Periocular and Iris (SBVPI) dataset.[10] The EEP dataset consists of 400 external eye images (2576×1934) of two different types (200 SCH images and 200 normal images), with SCH images displaying varying severities. The SBVPI dataset consists of 1840 normal external eye images (3000×1700).[11] All data is anonymized to ensure patient privacy, and Institutional Review Boards (IRB) approvals have been secured to protect human research subjects' rights.

External eye photos of various patients can be captured under diverse lighting situations, leading to disparities in brightness and color temperature levels. Such differences potentially impact the assessment and diagnosis of SCH. To address this issue, we employed automatic white balance algorithms that approximated the color temperature of the light source and modified the image colors accordingly.[12] The gray world assumption states that the average color of a scene or an image is perceived as gray or achromatic when viewed under normal lighting conditions. Thus, the average intensities of the red (R), green (G), and blue (B) channels in a scene or image are assumed to be equal.[13] By utilizing the gray world assumption, it was ensured that distinct images had comparable color temperatures.

Figure 1. (a) External eye images captured under varying color temperature and intensity conditions. (b) Corresponding photos after white balance correction, with enhanced intensity for easier identification.

TransUNet, a deep learning model for medical image segmentation, combines the strengths of transformer architectures and U-Net.[14] The self-attention mechanisms within the Vision Transformer (ViT) layers help capture long-range dependencies and global contextual information from the input images.[15] This significantly improves the model's ability to understand complex features in medical images and perform accurate segmentation tasks. In this work, the TransUNet model was customized to perform automatic and accurate segmentation of the reddish SCH area in the corresponding RGB eye images. This model is initialized using pre-trained weights from the ViT and is subsequently fine-tuned for the specific task of segmenting SCH areas.

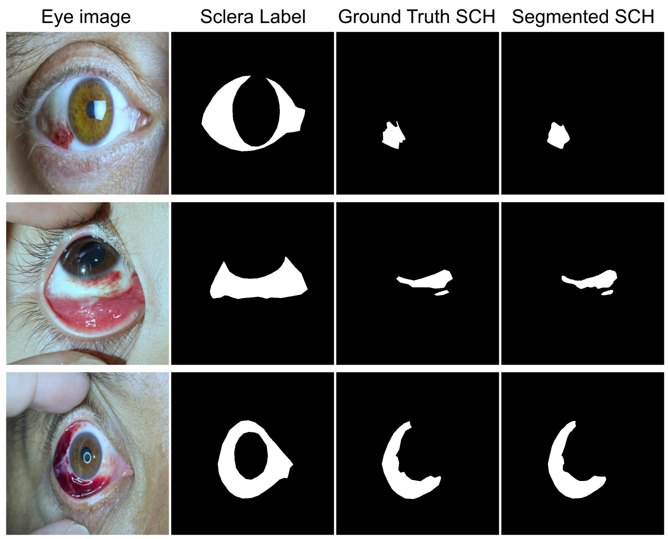

Figure 2. SCH area prediction and segmentation demonstrated in three external eye images, each displaying varying severity levels of SCH.

Regarding spectral reconstruction, our approach leverages transfer learning and a pre-trained model to reconstruct hyperspectral images from RGB images.[16,17] The pre-trained model's weights, derived from a large dataset, serve to improve the learning efficiency of the deep learning model. This strategy allows us to maximize the utilization of a limited dataset comprising external eye photos. From each RGB photo, we generate a set of 31 hyperspectral images covering the spectral range of 400 - 700 nm. These hyperspectral images exhibit the unique spectral signatures of different types of SCH, such as different stages in the blood reabsorption process. By analyzing these distinct spectral signatures, our approach enables accurate classification and assessment of the condition.

3. RESULTS

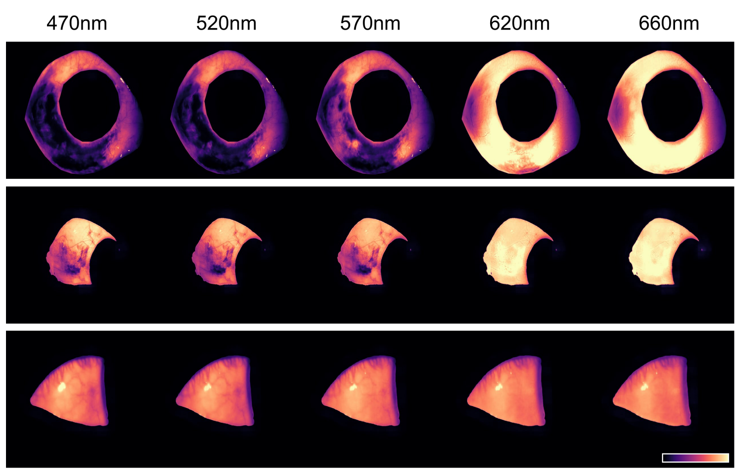

Figure 3. Visualization of hyperspectral reconstruction results generated from segmented scleral regions.

The utilization of different datasets enhances the approach's generalization capability and ensures that its performance is not biased. However, RGB eye photos from different datasets exhibit variations in color temperature, intensity, and contrast, as shown in Figure 1(a). To address this issue, we implement automatic white balance algorithms that estimate the color temperature of the light source and adjust image colors accordingly. This approach minimizes the impact of varying lighting conditions on image analysis and adjusts the intensity, as demonstrated in Figure 1(b).

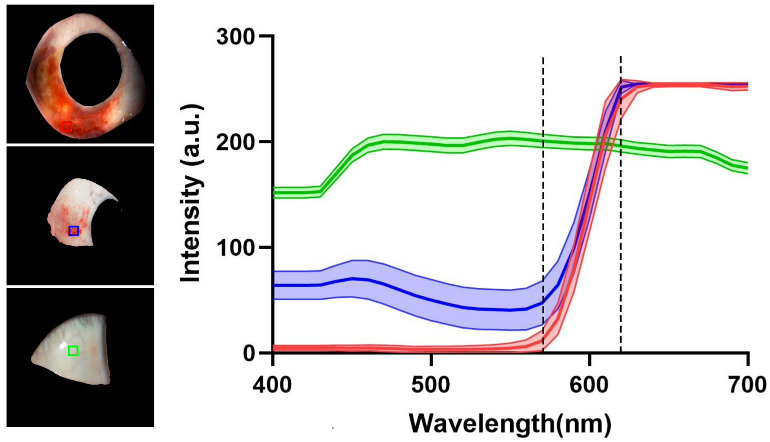

Figure 4. Spectral response curves of selected regions of interest (ROIs) derived from the reconstructed hyperspectral images.

Our proposed monitoring approach achieves an SCH segmentation accuracy of 96.2 % and an F1 score of 0.956. The inclusion of the sclera label effectively avoids interference from skin and eyelashes. This high level of accuracy enables healthcare professionals to precisely identify the affected area and minimize errors during the subsequent analysis of SCH progression (Figure 2).

The monitoring approach can generate 31 hyperspectral bands (ranging from 400 to 700 nm) by recovering the lost spectral information from a given RGB image. Five representative bands are visualized in Figure 3 by pseudo-color map. This process allows for a more detailed spectroscopic assessment of the affected area, capturing the subtle color changes associated with SCH healing. The ability to evaluate color changes is crucial for determining the stage of recovery and informs healthcare professionals about the patient's progress. This enhanced color change evaluation demonstrates the approach's potential to provide a more accurate and detailed assessment of SCH progression.

The rich spectral signatures obtained from the hyperspectral images enable the classification of SCH into three distinct stages, reflecting the blood reabsorption process (Figure 4). The regions of interest (ROIs) are marked in the RGB images, and the corresponding reconstructed spectra are demonstrated. The SCH affected regions have low intensity during 400 to 570 nm, and increase dramatically during 570 to 630 nm. This classification provides valuable insights into the healing process and helps healthcare professionals tailor their guidance and support accordingly.

4. DISCUSSION AND CONCLUSIONS

This work demonstrates the potential to bring some of the rich features of HSI to common RGB cameras, rather than relying on complex ophthalmic devices.[18,19] This approach can potentially improve patient care and promote better eye health through home inspections. The high accuracy in SCH segmentation, enhanced color change evaluation, and advanced classification and quantification of SCH progression showcase the potential of this approach to revolutionize the management of this prevalent ocular condition. The insights provided by this innovative method can aid healthcare professionals in making more informed decisions, reduce patient anxiety, and ensure more comprehensive monitoring of the condition.

In this paper, we present a deep learning-enabled monitoring approach that offers a promising method for the assessment and management of SCH. By leveraging spectral reconstruction and deep learning techniques, this approach enables the evaluation of the recovery process through spectroscopic and quantitative analysis, offering a more comprehensive and accurate means for assessing the severity, extent, and progression of the condition. It is important to note, however, that further research and validation of this approach in clinical settings are necessary to fully realize its potential and establish it as a standard tool for SCH monitoring and management. In the near future, we plan to develop the reconstructed spectra towards finer spectral resolution.

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