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A benchmark study of automated intra-retinal cyst segmentation algorithms using optical coherence tomography B-scans

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ABSTRACT

(Background and objectives): Retinal cysts are formed by accumulation of fluid in the retina caused by leakages from inflammation or vitreous fractures. Analysis of the retinal cystic spaces holds significance in detection and treatment of several ocular diseases like age-related macular degeneration, diabetic macular edema etc. Thus, segmentation of intra-retinal cysts and quantification of cystic spaces are vital for retinal pathology and severity detection. In the recent years, automated segmentation of intra-retinal cysts using optical coherence tomography B-scans has gained significant importance in the field of retinal image analysis. The objective of this paper is to compare different intra-retinal cyst segmentation algorithms for comparative analysis and benchmarking purposes.
(Methods): In this work, we employ a modular approach for standardizing the different segmentation algorithms. Further, we analyze the variations in automated cyst segmentation performances and method scalability across image acquisition systems by using the publicly available cyst segmentation challenge dataset (OPTIMA cyst segmentation challenge).
(Results): Several key automated methods are comparatively analyzed using quantitative and qualitative experiments. Our analysis demonstrates the significance of variations in signal-to-noise ratio (SNR), retinal layer morphology and post-processing steps on the automated cyst segmentation processes.
(Conclusion): This benchmarking study provides insights towards the scalability of automated processes across vendor-specific imaging modalities to provide guidance for retinal pathology diagnostics and treatment processes.

1. Introduction

A retinal cyst is a fluid-filled space in the retina. Medical studies show that visual acuity can be accurately predicted from the volume of retinal cystic fluids and their relative location in the retina [1]. Also, Cystoid macular edema (CME), caused by cysts in the retinal macular region, is the leading cause of central vision loss in the world today. CME develops when excess fluid accumulates within the retinal macula, which may lead to disruption of the retinal vessel barrier owing to pathologies such as age related macular degeneration, diabetic retinopathy, retinal vein occlusion and ocular inflammation. This process of fluid accumulation in retina can reduce macular retinal function [2] and can lead to irreversible blindness globally in individuals belonging to the economically productive age-group, irrespective of gender and demographics [3]. Further, visual acuity impairment due to CME can be correlated to the volume of the cystic fluid spaces and their location in retinal tissue [1]. Thus, automated quantification of retinal pathology severity is imperative towards timely retinal diagnostics and treatment.

CME can be clinically characterized using Optical Coherence Tomography (OCT) images [4]. OCT is a noninvasive imaging modality that is widely used for resolving internal structures of biological tissues, and for visualizing cross-sectional high-resolution images of the retina [5]. OCT images are extensively utilized for diagnostic and prognostic purposes for several retinal pathologies with manifestations that impact the intra-retinal micro-structure, such as cysts, exudates and retinal disorganization (see Fig. 1). However, one primary limitation of the OCT images is the manual assessment time required for analyzing the large volumes of image data

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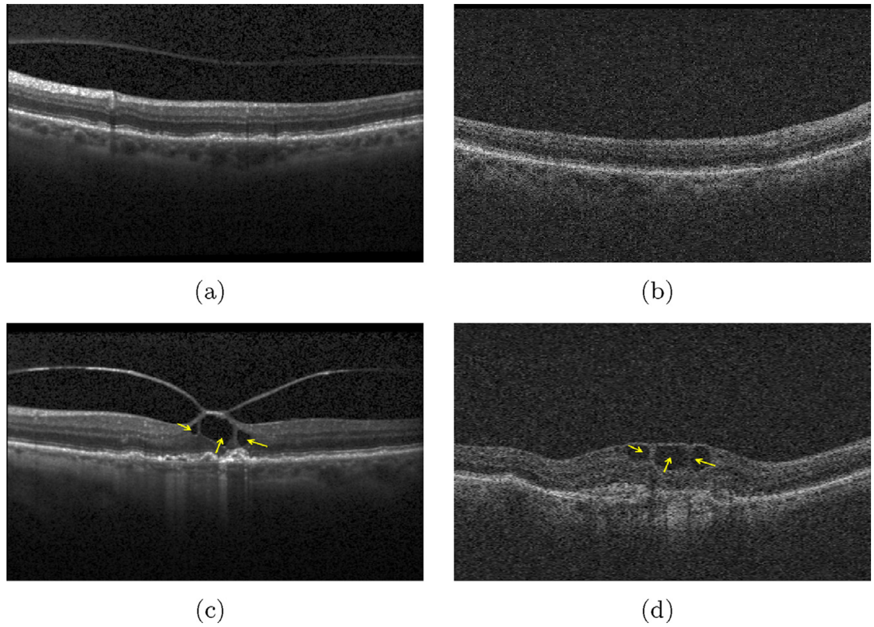

Fig. 1. OCT image of retina from two different vendors: (a),(b) Normal retina ; (c),(d) retina with cystoid macular edema. (Yellow colored arrow shows cystic fluids). (a) and (c) obtained from Spectralis imaging system, (b) and (d) obtained from Cirrus imaging system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

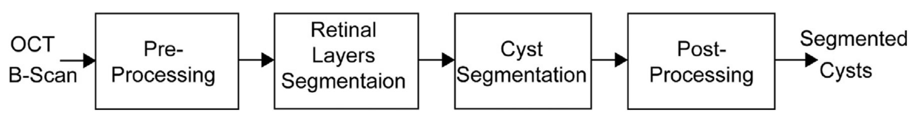

Fig. 2. Generic framework of automated intra-retinal cyst segmentation system.

per patient. This necessitates the development of automated intra-retinal and cyst segmentation/quantification methods to speed up the pathology characterization and diagnostic process. Several automation methodologies have been proposed in the recent past to address automated analysis of OCT images [1,6–10]. The key challenges posed by the OCT images to most existing methods for automated segmentation of cystic regions include pixel-level variabilities due to noise, image intensity variations, varied cyst morphology, confounding retinal structures and complex pathologies.

Based on the existing methods for automated cyst segmentation from OCT images, a generic methodological framework is proposed in Fig. 2. This framework consists of four main steps: (1) pre-processing; (2) retinal layer segmentation; (3) cyst segmentation and (4) post-processing. Since OCT images contain varying degrees of additive speckle noise, a pre-processing module is required for quality enhancement and equalization of the OCT images. Finally, the post-processing step is implemented to reduce the incorrectly segmented non-cystic regions (i.e., false positive regions). In this work, existing automated retinal cyst segmentation methods are standardized based on the work-flow shown in Fig. 2 and comparatively analyzed to evaluate the significance of the automated methods with respect to input data and output metrics.

This paper makes three key contributions. First, a modular approach to standardize existing OCT cyst segmentation methods is presented for methodological benchmarking purposes. The methodological contributions from significant automated OCT cyst segmentation methods are reviewed and comparatively discussed. Second, quantitative and qualitative analysis experiments are presented for evaluation of the existing automated OCT cyst segmentation methods. We observe that supervised OCT segmentation methods achieve higher cyst segmentation recall when compared to unsupervised approaches with degradation in segmentation precision across data sets with variable scan qualities. Third, OCT images from two different image acquisition systems are comparatively analyzed for scalability limitations owing to the image-level variabilities introduced by imaging systems. Such exhaustive analysis regarding the scalability of OCT cyst segmentation methods in terms of methodological and input data variations has not been presented so far. This work provides novel insights into the limitations of automated cyst segmentation tasks for retinal diagnostic and screening purposes.

The organization of this paper is as follows. In Section 2, the materials and evaluation metrics used for comparison study are presented. In Section 3, methods considered for comparative study are briefly reviewed. In Section 4, the experimental setup is discussed. In Section 5, the experimental results of the proposed methods are presented. Conclusions and discussion regarding the comparative assessment of the automated intra-retinal cyst segmentation along with future research directions are presented in Section 6.

2. Materials

2.1. Dataset

This work comparatively analyzes existing automated intra-retinal OCT cyst segmentation methods on the publicly available OPTIMA cyst challenge OCT dataset [11]. This dataset contains OCT scans obtained from CME subjects using four different imaging systems, namely Zeiss Cirrus, Nidek, Spectralis Heidelberg and Topcon. In this work, OCT scans from Cirrus and Spectralis image acquisition systems are analyzed, since the data sets from these systems demonstrate moderate to severe pathological features when compared to the other imaging systems. The selected OCT scans are acquired over 6×6 mm of the macula and foveal center from subjects with CME. The OCT frames represent gray-scale images