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Semi-automated quantification of retinal IS/OS damage in en-face OCT image

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ABSTRACT

A variety of vision ailments are indicated by structural changes in the retinal substructures of the posterior segment of the eye. In particular, integrity of the inner-segment/outer-segment (IS/OS) junction directly relates to the visual acuity. In the en-face optical coherence tomography (OCT) image, IS/OS damage manifests as a dark spot in the foveal region, and its quantification, usually performed by experts, assumes diagnostic significance. In this context, in view of the general scarcity of experts, it becomes imperative to develop algorithmic methods to reduce expert time and effort. Accordingly, we propose a semi-automated method based on level sets. As the energy function, we adopt mutual information which exploits the difference in statistical properties of the lesion and its surroundings. On a dataset of 27 en-face OCT images, segmentation obtained by the proposed algorithm exhibits close visual agreement with that obtained manually. Importantly, our results also match manual results in various statistical criteria. In particular, we achieve a mean Dice coefficient of 85.69%, desirably close to the corresponding observer repeatability index of 89.45%. Finally, we quantify algorithmic accuracy in terms of two quotient measures, defined relative to observer repeatability, which could be used as bases for comparison with future algorithms, even if the latter are tested on disparate datasets.

1. Introduction

With the advent of *optical coherence tomography* (OCT) [1], ophthalmologists have been able to image as well as assess pathological changes in the posterior segment of the eye [2]. Specifically, the *spectral domain OCT* (SD-OCT) has enabled improved visualization and segmentation of retinal layers, almost similar to histology [3], and consequently, various significant clinical studies. For example, the integrity of the hyper-reflective inner-segment/outer-segment (IS/OS) junction of photoreceptorsin SD-OCT B-scans has been found to correlate with visual acuity in various retinal disorders [4–6]. In particular, recent investigations have shown such association in patients with parafoveal telangiectasia [7], retinitis pigmentosa [8], Stargardt's disease [9], retinal vein occlusion [10], age-related macular degeneration (AMD) [11], resolved central serous chorioretinopathy [12], and diabetic macular edema [13].

The aforementioned reports include evaluation of horizontal and/or vertical B-scans of the macular area. Typical SD-OCT B-scan is shown in Fig. 1(a), consisting of retina (layered), including IS/OS junction, choroid (granular), and sclera (smooth), from top to bottom (physiologically from inner to outer layer) [14]. Unfortunately, a single foveal B-scan provides only a general idea about visual acuity, and does not convey holistic information about the entire macular region. For instance, OCT B-scan depicted in Fig. 1 (b) provides only a cross-sectional view of the condition of IS/OS layer present at foveal center, which is clearly not sufficient to visualize the complete topography of the lesion. In this backdrop, an SD-OCT-based technology, called en-face visualization (also called a transverse-, coronal-, or C-scan) of specific layers of the retina including the IS/OS, assumed significance [15,16]. Fig. 1 (c) depicts the en-face OCT image taken at the IS/OS junction from volumetric B-scans, where the dark region at the center indicates the damaged IS/OS region. Clearly, an en-face OCT image provides better visualization of the damaged region compared to B-scans.

Indeed, the extent of damage in IS/OS region, estimated from en-face OCT images of the posterior part of the eye, has emerged as an important metric in disease management [17]. Accurate quantification of damaged IS/OS region on en-face images provides

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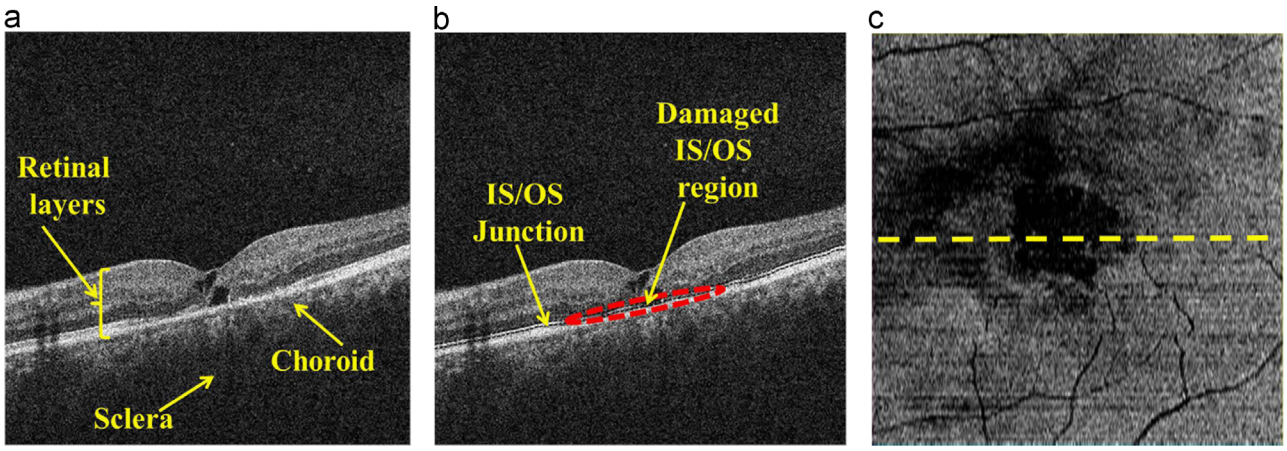

Fig. 1. (a) OCT B-scan (cross-sectional view): various retinal layers, choroid and sclera; (b) IS/OS layer, with damaged region encircled; and (c) en-face OCT of IS/OS layer with the B-scan location marked by dashed line.

information about the extent of the damage, and helps in early diagnosis of extrafoveal diseases, monitoring of disease progression and evaluation of treatment response. Consequently, estimation accuracy has assumed a vital role in ensuring accurate diagnostic outcome. So far, such area measurements have been performed by experts by manually delineating the damaged region boundaries and then measure the area [18,19]. Generally, an expert labels multiple en-face OCT images per subject to evaluate disease progression and treatment response, making this procedure time consuming, laborious as well as susceptible to fatigue-induced error. Further, since the number of available experts is often few compared to the number of subjects (especially, in developing regions), only a fraction of potential subjects actually receive the aforementioned diagnosis. Against this backdrop, automated quantification of IS/OS layer lesion could be crucial in reducing professional effort and time per subject, potentially allowing more subjects to obtain specialized medical attention. Automation would also avoid human error induced by fatigue and tedium. Accordingly, we propose a semi-automated algorithm for damaged IS/OS region segmentation and related area measurements. In particular, we adopt a level-set approach towards lesion segmentation. At the heart of our technique lies an energy function, chosen as the estimated mutual information between rival classes, which is iteratively minimized. Upon meeting a suitable stopping criterion, the zero-level contour of the level-set function is taken as the decision boundary. Advantages of the level-set method over conventional statistical pixel classification techniques arise from the former's ability to achieve global smoothness while seamlessly handling changes in topology [20].

Our algorithm is evaluated on a dataset consisting of 27 en-face OCT images taken from 20 patients with *idiopathic juxtafoveal retinal telangiectasia* (IJRT) type 2A, each covering 6×6 mm^2 area centered around fovea. Further, damaged area measurements obtained using the proposed method are compared with that obtained manually. We take the average of the two manual segmentations performed by the same expert as the reference following current clinical practices [21,22], and perform both qualitative and quantitative performance assessment. First we visually compare the algorithmic segmentation of the damaged region vis-à-vis the manual reference. Subsequently, we turn to quantitative assessment of the proposed semi-automated algorithm in terms of estimation accuracy of the damaged area. Specifically, we quantify estimation accuracy in terms of Dice coefficient (DC), which measures the closeness between the algorithmic and the manual delineations. Ideally, one wishes algorithms to perform as well as the manual method. To quantify the closeness to this ideal goal, we present a thorough statistical analysis. Specifically, we obtain mean DC of 85.69%, which is close to the corresponding observer repeatability value of 89.45%. Further, to provide a basis for performance comparison against future techniques, which will possibly be evaluated on disparate datasets, we define two statistical measures (i) quotient of mean and (ii) quotient of coefficient of variation, where the term quotient indicates ratio of automated to manual indices. Specifically, we calculate the respective quotient of mean Dice coefficient (QMDC) and quotient of coefficient of variation of Dice coefficient (QCVDC), for each of which smaller value is better, and the value of one signifies a level of performance at par with that of human expert. Encouragingly, we achieve respective quotient values of 1.35 and 1.09, signifying the efficacy of the proposed algorithm.

In summary, our main contributions are as follows:

1. A semi-automated method based on level sets is demonstrated for delineating IS/OS damage.
2. Algorithmic delineation of the damaged region is evaluated for accuracy vis-à-vis manual delineation using thorough statistical analysis based on Dice coefficients.
3. Quotient measures are introduced to facilitate comparison among algorithms that are tested on disparate datasets.

The rest of the paper is organized as follows. The en-face OCT image acquisition technique is presented in Section 2.1, and the problem formulation and the proposed methodology are presented in Section 2.2. In Section 3, results illustrating segmentation using the proposed method, and subsequently extensive statistical analysis of estimation accuracy is presented. Finally, Section 4 concludes the paper with a discussion.

2. Materials and methods

2.1. En-face OCT acquisition of IS/OS layer

The present study was performed at L.V. Prasad Eye Institute, India, between December 2012 and June 2013. Approval from the Institutional Review Board of the institute was obtained and the subjects provided their informed consent. Further, this study was conducted in accordance with the tenets of the Declaration of Helsinki. In particular, we considered 20 patients diagnosed to have idiopathic juxtafoveal retinal telangiectasia (IJRT) type 2A, based on SD-OCT scans. Detailed biomicroscopic examination and fundus fluoscein angiography were performed to confirm the