Diagnostics of Optic Nerve Head Pathologies using Structural Analysis of Eye Ultrasound B-scan Images

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Keywords: Eye B-scan Image, Structural Image Analysis, Optic Nerve Head, Drusen.

Abstract: Optic nerve head drusen are congenital and developmental anomalies in a form of calcific degeneration in some of axons of the optic nerve head. Diagnostic difficulties may be encountered when drusen are buried deep within the nerve tissue in the optic nerve head, as they can resemble optic disc swelling or other pathologies. Diagnosing optical disc drusen correctly is important to avoid unnecessary work-up and to avoid overlooking potential serious conditions such as true papilledema. We propose the method based on structural analysis of the eye B-scan images combined with mathematical morphology to reveal valuable estimates reflecting pathogenic changes in the optic nerve and surrounding structures for improvement of diagnostic quality.

1 INTRODUCTION

Optic nerve head (or optic disk) drusen are congenital and developmental anomalies in a form of calcific degeneration in some of axons of the optic nerve head (Davis and Walter, 2003). Due to that visual acuity is usually not affected but visual fields of patients can be abnormal and deteriorate over time (Davis and Walter, 2003). Drusen of the optic disc may be easily diagnosed when glowing yellow hyaline bodies are visible during ophthalmoscopy. However, diagnostic difficulties may be encountered when drusen are buried deep within the nerve tissue in the optic nerve head, as they can resemble optic disc swelling based on the ophthalmoscopic appearance alone (Kurz-Levin and Landau, 1999). Optic disk swelling may be associated with raised intracranial pressure that is transmitted to subarachnoid space surrounding an optic nerve, thereby interrupting metabolic processes of the nerve and consequently leading to edema and eventual visual impairment or loss (Passi et al., 2013). Differentiation of optic disc edema caused by papilledema or other optic neuropathy from optic nerve head drusen is very important clinically. However, using for that B-scan ultrasonography, and even fluorescein angiography or computed tomography (CT) remains problematic (Johnson et al., 2009) Misleading diagnostic conclusions could be made in differentiation of optic nerve edema, drusen covering the optic nerve head and combined optic nerve edema and drusen cases. Diagnosing optical disc drusen correctly is important to avoid unnecessary work-up and to avoid overlooking potential serious conditions such as true papilledema. Kurz-Levin and Landau (1999) reviewed retrospectively the clinical records of 142 patients (261 eyes) with suspected drusen of the optic disc and stated that drusen of the optic nerve head are diagnosed most reliably using B-scan echography compared with both pre-injection control photography and CT scans.

Structural analysis of the eye B-scan images combined with mathematical morphology methods can reveal valuable estimates reflecting pathogenic changes in the optic nerve and surrounding structures. The idea of this study was to elaborate a method for computer-assisted evaluation of eye B-scan ultrasonography images providing optimal objectivized estimates for optic nerve head diagnostics.

The proposed estimates should allow differentiation of following cases: i) optic nerve

Kriščiukaitis, A., Valuckis, V., Kybartaitė-Žilienė, A. and Kriaučiūnienė, L.
Diagnostics of Optic Nerve Head Pathologies using Structural Analysis of Eye Ultrasound B-scan Images.
DOI: 10.5220/0005762301010104
In *Proceedings of the 9th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2016) - Volume 2: BIOIMAGING*, pages 101-104
ISBN: 978-989-758-170-0

edema; ii) drusen covering the optic nerve head; iii) combined optic nerve edema and drusen.

2 METHODS

2.1 Image Data Sample

B-scan ultrasound eye images were registered in Department of Ophthalmology of Lithuanian University of Health Sciences Hospital by means of OTI-Scan 1000 ultrasound scanner (Optos, USA), at 10 MHz frequency. An expert-ophthalmologist selected 11 typical images representing drusen at the optic nerve head cases, 3 typical images as representing optic nerve edema cases, and 5 images – combined drusen and edema cases.

2.2 Structural Analysis of the Images

The structural analysis algorithm of the eye B-scan images is presented on the left of Figure 1. The whole image firstly is filtered using mathematical morphology operations "opening" and "closing" (Najman and Talbot, 2010) discarding registration noise and filling the gaps in area represented by white pixels beyond the retinal surface. Count of white pixels in every row of the image-representing matrix forms array, which has local minima at the level of optic nerve (see the graph on the right of Figure 1). Boundaries of this hollow are considered as preliminary boundaries of the optic nerve zone. We search for the pixels representing retinal surface in every row of image-representing matrix. They are found as the first maximal contrast points to the right from the center of an image. Knowing *a priori* that the zone of the optic nerve can be elevated in regard to retinal surface due to edema, we exclude rows of preliminary detected optical nerve zone from this procedure. A retinal surface is expected to be round shaped, so we best fit part of the ellipse to detected retinal surface representing pixels. The final estimation of a width of the optic nerve is performed at 3 mm depth from the fitted ellipse according to maximal gradient of pixel values at this depth (shown by two white dots on B-scan image in Figure 1). The final detection of the optic nerve zone is done using these points. Pixels from rows of image array from this zone are used for further analysis.

2.3 Diagnostic Feature Estimation and Analysis

Elevation of the optic nerve head in regard to the retinal surface is the first feature. It is estimated as the area between fitted ellipse, representing retinal surface and the detected real optic nerve surface (bold white dots on B-scan image in Figure 1). The optic nerve drusen are represented by aggregates of white pixels, when certain elevation is present. However heuristic approach to construct decision rules for identification of analyzed pathological structures became sophisticated and we found it as not reliable during preliminary tests. Therefore we performed statistical analysis of the pixel values from the zone of the optic nerve. Following features were selected and estimated for further analysis: normalized counts of histogram at standardized 21 bins covering the most expected range of pixel values together with the main descriptive statistic parameters of the pixels - mean; variance; skewness;

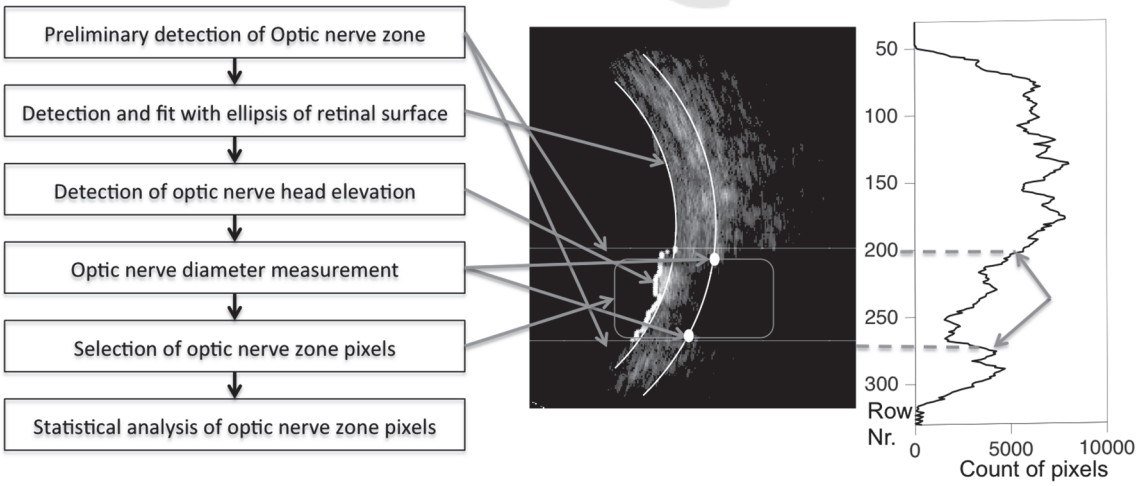

Figure 1: The algorithm of structural analysis of B-scan eye images (left), illustration of its result (center). Count of white pixels in every row of the image, used for preliminary detection of the optic nerve zone is shown on the right graph.

Table 1: Eigenvalues of canonical functions.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	134,070	93,2	93,2	0,996
2	9,820	6,8	100,0	0,953

Table 2: Wilks' Lambda criterion for canonical functions.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0,001	61,941	24	0,000
2	0,092	20,242	11	0,042

kurtosis and entropy (26 parameters in total for every analyzed picture). We normalized values of all features dividing them by estimate of their spread (difference between the maximum and minimum). Discriminant analysis was used to construct canonical discriminant functions best classifying data reflecting analyzed cases ("drusen", "drusen and edema", "edema"). The canonical function involves several initial features optimizing their weight for the best separation of groups. The typical canonical function is:

$$Y_i = l_1 X_1 + l_2 X_2 + \ldots + l_p X_p + C_i , \quad (1)$$

where X are the features and l are their weights. Quality of classification using canonical functions was determined by Wilk's Lambda statistics. For details about discriminant analysis see (Klecka, 1980). All calculations were performed using IBM SPSS Statistics 22 package.

3 RESULTS

Typical examples of eye B-scan images with determined main eye structures in case of "drusen", "drusen and edema" and "edema" are shown in Figure 2. Twelve of 26 initial features were involved constructing two canonical functions for data classification according Fisher statistics and Wilk's Lambda criterion. Percentage of variation covered by every canonical function is reflected by corresponding eigenvalue of co-variation matrix presented in Table 1.

Quality of classification determined by Wilk's Lambda criterion is presented in Table 2. As we see, values of Wilk's Lambda criterion are below 0.1 and significance values are below 0.05 for both canonical functions, what means that both of them could be used for classification. However, according to eigenvalues and percentage of variation covered (93.2% vs. 6.8%), we can recommend the 1st canonical function for classification of the cases. Standardized canonical discriminant function coefficients are presented in Table 3.

Table 3: Standardized Coefficients of Canonical Discriminant Function.

Variables	Functions	
	1	**2**
VAR3	19,976	-3,643
VAR4	3,554	6,430
VAR5	11,114	4,164
VAR6	6,823	-5,266
VAR7	12,205	-3,969
VAR8	-1,619	2,627
VAR9	-6,323	8,439
VAR10	24,528	-13,592
VAR11	17,923	10,234
VAR12	-13,304	-0,878
VAR13	25,300	-9,504
VAR15	2.835	6.142

It is interesting that only certain histogram counts were selected to include into canonical functions. Maximal values of coefficients indicate the most important features for classification of the cases. As we see, the 3rd, the 10th and the 13th histogram counts were found as the most significant. All 100% of original grouped cases were correctly classified. However, only 58,8% of cross-validated grouped cases were correctly classified. Stepwise selection of features for classification according to Fisher statistics, using minimum partial F to enter 3.84 and maximum partial F to remove 2.71, selected variance of pixel values as the only feature useful for classification. In this case 76.5% of original grouped cases were correctly classified. Involvement of neither optic nerve head elevation estimate nor optic nerve diameter at 3 mm depth into features set did not improve the classification results.

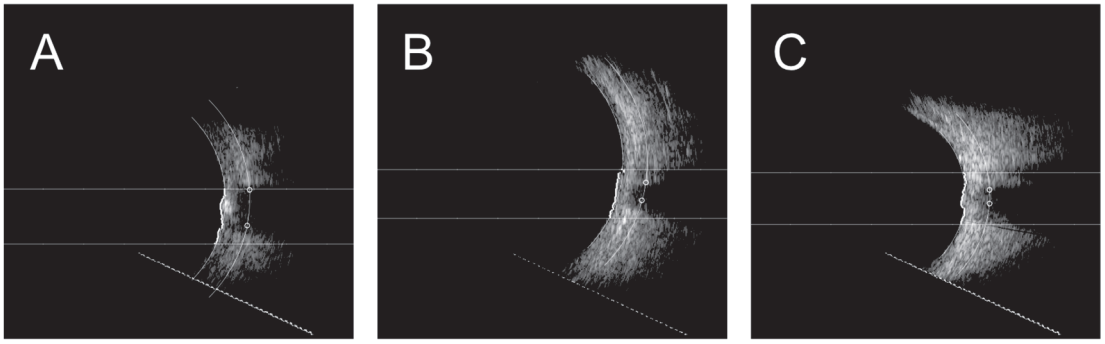

Figure 2: Examples of eye B-scan images with determined main eye structures in cases of A: “drusen”, B: “edema” and C: “drusen and edema”.

4 DISCUSSION

The elaborated algorithm for data preprocessing and structural analysis of ultrasound eye B-scan images extracts subset of pixels, representing the zone of interest – the area of the optic nerve close to the retinal surface. Estimated statistical parameters of pixels were shown as informative features for differentiation between the three clinical cases. Constructed canonical functions correctly classifying all three clinical cases revealed the main features to be considered when analyzing ultrasound eye B-scan images. Classification significance was acceptable. However very limited number of cases has been analyzed so far and it is the weakest point of this study. Nevertheless elaborated set of data preprocessing and structural analysis algorithms together with proposed methods of statistical analysis forms a basis for future investigations including more representative sample of images covering a wide range of clinical cases.

The elaborated structural analysis algorithm determines key-structures in the eye B-scan images. We expect that it would be useful for feature estimation in semi-automated or automated diagnostics of other pathologies in the eye.

5 CONCLUSIONS

The elaborated method of computer-assisted evaluation of eye B-scan images provides the optimal set of features for diagnostics of pathologies in the optic nerve head. We demonstrated its suitability on limited number of pathologies, but it could be used in many other cases, where diagnostics is based on analysis of eye B-scan images.

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