COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 130 (2016) 186–197

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

iDEAS: A web-based system for dry eye assessment

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ARTICLE INFO

Article history:
Received 4 September 2015
Received in revised form
1 February 2016
Accepted 22 February 2016

Keywords:
Medical application
Web-based system
Vision sciences
Dry eye syndrome
Image analysis
Pattern recognition

ABSTRACT

Background and objectives: Dry eye disease is a public health problem, whose multifactorial etiology challenges clinicians and researchers making necessary the collaboration between different experts and centers. The evaluation of the interference patterns observed in the tear film lipid layer is a common clinical test used for dry eye diagnosis. However, it is a time-consuming task with a high degree of intra- as well as inter-observer variability, which makes the use of a computer-based analysis system highly desirable. This work introduces iDEAS (Dry Eye Assessment System), a web-based application to support dry eye diagnosis.
Methods: iDEAS provides a framework for eye care experts to collaboratively work using image-based services in a distributed environment. It is composed of three main components: the web client for user interaction, the web application server for request processing, and the service module for image analysis. Specifically, this manuscript presents two automatic services: tear film classification, which classifies an image into one interference pattern; and tear film map, which illustrates the distribution of the patterns over the entire tear film.
Results: iDEAS has been evaluated by specialists from different institutions to test its performance. Both services have been evaluated in terms of a set of performance metrics using the annotations of different experts. Note that the processing time of both services has been also measured for efficiency purposes.
Conclusions: iDEAS is a web-based application which provides a fast, reliable environment for dry eye assessment. The system allows practitioners to share images, clinical information and automatic assessments between remote computers. Additionally, it save time for experts, diminish the inter-expert variability and can be used in both clinical and research settings.

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http://dx.doi.org/10.1016/j.cmpb.2016.02.015
0169-2607/

1. Introduction

Dry eye disease (DED) is a widespread syndrome that affects between 10% and 35% of the population [1] and can reduce ocular comfort and visual performance. It contributes to contact lens wear discomfort [2], being the leading cause of contact lens discontinuation [3]. DED affects quality of life, and also has effects on ocular and general health, perception, visual function and vision [4]. The impact on quality-of-life has been rated as similar to the effect of moderate angina [5] or dialysis [6].

The Dry Eye Workshop redefined DED by including implementations such as symptoms of visual disturbance, osmolarity as the leading factor of DED, and the inflammation in the pathogenesis of DED [4]. They also classified DED in two major classes: aqueous tear-deficient dry eye and evaporative dry eye. In the first one, there are insufficient tears secreted by the lachrymal glands, and this encompasses Sjögren syndrome (an autoimmune disease) and non Sjögren. Evaporative dry eye occurs when there is excessive water loss from the exposed ocular surface. Even though this classification, aqueous tear-deficient dry eye and evaporative dry eye may co-exist and have features in common, including increased tear film osmolarity and reduced stability [4].

Because of its multifactorial origin, DED can manifest in a variety of ways [7] and, thus, it is difficult to diagnose it. In effect, there is no single clinical diagnostic test to reliably distinguish individuals with and without DED [8]. Therefore, various assessment techniques should be carried out in order to be able to manage the patient appropriately [9].

The tear film is a complex, dynamic structure of lipids, proteins, and mucins riding on the hydrophobic surface of the epithelium. A three-layered structure of the tear film was initially described by Wolff [10], comprising an inner mucous layer (0.2% of the whole thickness 0.02–0.04 μm), an intermediate aqueous layer (99% of the whole thickness 7 μm), and a superficial oily layer called the lipid layer (0.02% of the whole thickness 0.08 μm) [10]. The lipid layer of the tear film, composed by lipids from the Meibomian glands, plays a major role in retarding water evaporation during the inter-blink period [11] and is the main factor in the evaporation rate of the tear film, followed by the protein constituent of the tear film, the mucin coating of the epithelial cells, and the aqueous component of lachrymal secretions [12]. The Tear Film and Ocular Surface Society (TFOS) launched the International Workshop on Meibomian Gland Dysfunction, in which it was suggested that "Meibomian oil deficiency" is an intrinsic factor associated with the evaporative DED [13], with Meibomian glands as a key component in the etiology of dry eye which contributes to the evaporative status of the tear film. On the other hand, it is well-reported thick tear film lipid layers correlate with better tear stability [14], being the optimum thickness between 90 nm and 150 nm, with average thickness between 60 nm and 75 nm. However, if a lipid layer thickness is lower than 60 nm, it is considered thin and prone to tear evaporation [14,15]. Therefore, the assessment of lipid layer thickness should be a useful clinical test.

The Tearscope Plus (Keeler Ltd., UK) was designed by Guillon for rapid assessment of lipid layer thickness [16]. It projects a cylindrical source of cool white fluorescent light onto the lipid layer allowing observation of the superficial layer by thin-film interferometry. Thus, any observed phenomena are unique to the specific light source of the Tearscope Plus. The thickness and regularity of the lipid layer is categorized by observing the appearance and color of the interference pattern between the lipid layer and underlying layers. The instrument used in conjunction with a non-illuminated biomicroscope provides adequate magnification of the image. Guillon also proposed five main grades of lipid layer thickness interference patterns for observations made using the Tearscope Plus [16]: open meshwork (10–20 nm), closed meshwork (20–50 nm), wave (50–70 nm), amorphous (80–90 nm) and color fringe (90–180 nm). Other patterns associated with ocular pathology often appear as abnormal color fringes, referred as globular patterns (>180 nm) [17,18].

Thick lipid layers (>90 nm) are readily observed since they produce color and wave patterns. However, thin lipid layers (<60 nm) are difficult to visualize, since color fringes and other distinct morphological features are not present and observations are affected by the subjective interpretation of the observer [15]. Although the Tearscope Plus has proven its validity [18], some amount of training is needed to interpret lipid layer patterns. This difficulty in interpreting lipid layer patterns (especially the thinnest ones) and the lack of a huge bank of images for reference purposes has meant that many eye care professionals have abandoned this test.

Another devices for lipid layer thickness have been designed, such as the Doane's interferometer, DR-1 camera, or the LipiView interferometer. The Doane's interferometer [19] consists of a light source and an observation system, and captures images using a video-based system. An overall observation of the tear film with white light allows classification into five distinct patterns based on the texture and color properties: strong fringes, coalescing strong fringes, fine fringes, coalescing fine fringes, and debris. These features suggested groups described in terms of "strong" fringes, with either a regular pattern or a broken pattern; "fine" fringes, with very little color differentiation; and "debris", indicating small to medium disturbances within the underlying pattern. However, this useful technique is difficult to carry out due to the inconsistency in analyzing the images. Significant changes can occur in a relatively short time intervals, resulting in successive images that can be dramatically different from each other [19,20].

DR-1 camera [21,22] is an instrument that allows to obtain interferometric images of the tear film lipid layer. It is assumed that all light from the DR-1 light source through the convex lens would be reflected at the surface and at the back of the tear lipid layer with the normal incidence specular angle within a range of the 8-mm diameter of the cornea. The evaluation of tear interference images was carried out in five steps: grade 1, somewhat gray color, uniform distribution; grade 2, somewhat gray color, non-uniform distribution; grade 3, a few colors, non-uniform distribution; grade 4, many colors, non-uniform distribution; and grade 5, corneal surface partially exposed. Normal control eyes are classified into grades 1 and 2, while dry eyes are classified into grades 2, 3, 4, and 5 [21,22]. However, it was found that the color intensity of interference