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Medical image classification based on artificial intelligence approaches: A practical study on normal and abnormal confocal corneal images

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ABSTRACT

Corneal images can be acquired using confocal microscopes which provide detailed views of the different layers inside a human cornea. Some corneal problems and diseases can occur in one or more of the main corneal layers: the epithelium, stroma and endothelium. Consequently, for automatically extracting clinical information associated with corneal diseases, identifying abnormality or evaluating the normal cornea, it is important to be able to automatically recognise these layers reliably. Artificial intelligence (AI) approaches can provide improved accuracy over the conventional processing techniques and save a useful amount of time over the manual analysis time required by clinical experts. Artificial neural networks (ANNs), adaptive neuro fuzzy inference systems (ANFIS) and a committee machine (CM) have been investigated and tested to improve the recognition accuracy of the main corneal layers and identify abnormality in these layers. The performance of the CM, formed from ANN and ANFIS, achieves an accuracy of 100% for some classes in the processed data sets. Three normal corneal data sets and seven abnormal corneal images associated with diseases in the main corneal layers have been investigated with the proposed system. Statistical analysis for these data sets is performed to track any change in the processed images. This system is able to pre-process (quality enhancement, noise removal), classify corneal images, identify abnormalities in the analysed data sets and visualise corneal stroma images as well as each individual keratocyte cell in a 3D volume for further clinical analysis.

1. Introduction

Confocal microscopy is a major advance in comparison with normal light microscopy since it allows the user to see not only deep into cells and tissues, but also to create images in three dimensions. The major difference in principle between the optics of a conventional microscope and that of a basic confocal microscope is the presence in the latter of a confocal pinhole, which allows only light from near the point of focus to reach the detector. The resulting advantage of a confocal microscope over a conventional microscope is the production of a series of images (in X–Y) at different depths (Z) in the object, less affected by out-of-focus information. Such a series of images (a stack) is a three dimensional representation of the object being viewed, produced by optical (as opposed to physical) sectioning [1].

The corneal images employed in this work were acquired using a NIDEK Confoscan 4 microscope, which uses a confocal slit. Further details about these data sets are presented in Section 3.5. This microscope has the following main features. It has fully automated alignment and scan time is optimised to produce 350 images in around 15 s. It has nine internal fixation targets for increased patient fixation stability and device performance. An optional Z-ring attachment is available for this microscope which increases the stability of the examination and the reliability of the Z-scan reference for accurate full thickness optical pachymetry. This feature offers an ability to define the position of any corneal structure and opacity with high precision [2].

The main anatomical structure of the human eye is shown in Fig. 1. The cornea is the convex and transparent part of the front of the eye; it provides most of the focusing power required to form the image on the retina. The cornea is a complex 3D structure. It has three main layers separated by two thin membranes, which are (from the anterior to posterior): epithelium (thickness about 50 μm), Bowman's membrane, Stroma (thickness about 400 μm),

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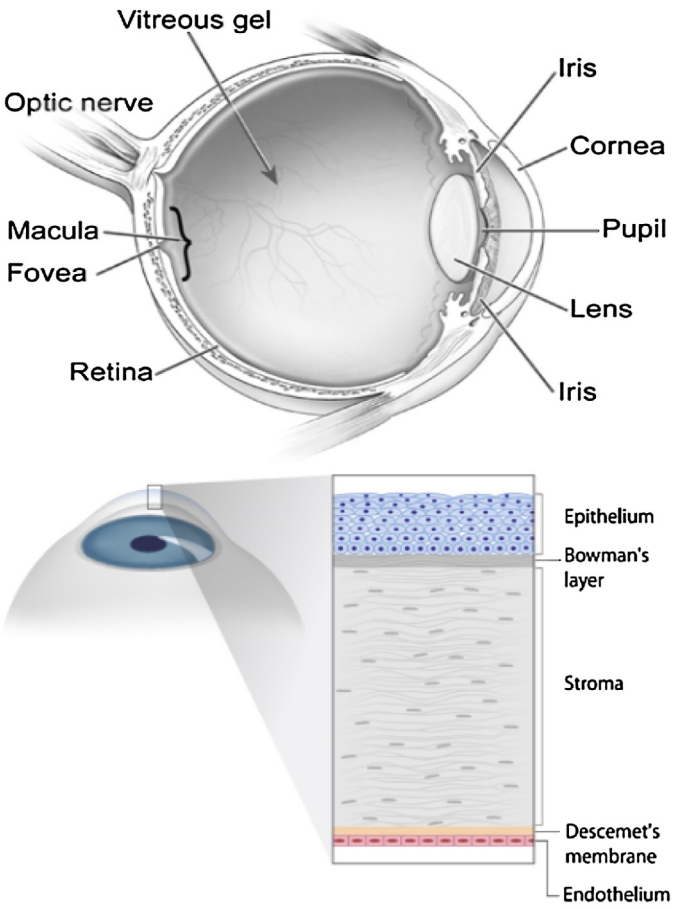

Fig. 1. The anatomical structure of the human eye and a section through the cornea showing the corneal layers [3].

Descemet's membrane, and Endothelium (thickness about 30 μm). Injuries, dystrophies, and diseases can adversely affect the cornea and lead to visual impairment which can be as severe as complete blindness. Due to the development and increased availability of in vivo confocal microscopes, ophthalmologists can observe the living human eye in situ at the cellular level which overcomes some of the limitations of conventional light and electron microscopy [3].

The confocal images can be used to construct three-dimensional models of the corneal layers as each image contains a slice of information acquired at a new depth. However, there are several challenges in the way of processing and reconstructing meaningful 3D models from corneal images. For example, the small movements of the eye during the scanning process due to respiration, cardiac pulse, and other factors cause images of adjacent layers to be displaced laterally (in X and Y) and axially (Z). Corneal images also contain significant amounts of noise and intensity variations both within and between images due to variation of illumination over the field of view and differences in reflectivity of the corneal layers. Accurate classification of the three main corneal layers is very important, as each of these layers has a unique structure which in turn requires an appropriate processing procedure to extract the information, which can benefit ophthalmologists (saving them evaluation time and provide some clinically useful factors/parameters) and hence patients. In addition, the classification of abnormal corneal cases is vital to aiding the detection of disease and identifying the affected layer as early as possible, which can lead to better treatment for the patient.

The confocal microscope's generation of a large number of images per patient per scan, makes their analysis a challenging task for an ophthalmologist with a large number of patients in a busy clinical setting. Ophthalmologists could use an efficient system to reduce the analysis time and speed up the treatment process, by giving them the opportunity to look at individual layers on demand, leading to faster and more accurate diagnosis. For example, looking at the stroma layer in 3D could save time, as issues related to the keratocyte cells could be identified by analysing one figure instead of looking at the large number of individual images representing the stroma layer. Based on these ideas our research is aiming to develop a robust system able to analyse confocal corneal data sets, identify abnormalities associated with this data and offer easier clinical analysis through the 3D stroma cell presentation. This aim is to be achieved through the following objectives: first, an efficient preprocessing approach which enhances the quality of the processed confocal images, reduces the level of the noise in these images, and eliminates redundant images; second, an artificial intelligence approach to improve the recognition accuracy of the corneal images into one of the epithelium, stroma and endothelium layers; third, identify abnormalities in the analysed corneal data sets; fourth, 3D visualisation of the whole stroma layer as well as for each individual keratocyte cell for further clinical analysis. This would help the day to day clinical practice in a better understanding of common corneal pathologies of a certain layer in the cornea.

The rest of this paper is organised as follows. Section 2 presents the current corneal state of the art research and clinical practices. Descriptions of the normal and abnormal data sets employed in the work, the research methodology as well as system development are presented in Section 3. Section 4 presents the practical implementation and the results achieved by automated analysis, abnormality analysis and image visualisation. Finally, Section 5 presents the conclusions.

2. Current state of the art

The existing literature on confocal microscope related corneal image processing and classification is rather limited and includes the following examples. The work presented in [4] on automatic recognition of cell layers in corneal confocal microscopy images is based on image binarisation followed by a description of cell shape obtained using Hu variables. An artificial neural network is employed to classify each image into the three corneal main layers in normal subjects. The resulting system was tested on 46 corneal images. The work presented in [5] addressed the problem of obtaining a 3-dimensional (3D) reconstruction of the cornea starting from a set of confocal microscope images by producing an image stack. Here a registration procedure based on normalised correlation is applied to each image. This method was intended to overcome the effects of eye movements which occur during image acquisition. Removing these shifts in image X and Y directions, a 2D image stack is reconstructed.

In the work presented in [6], a programme was written to calculate the cell densities in confocal images obtained from two types of confocal microscopes: the ConfoScan 4 (Nidek, Inc., Freemont, CA), and the Tandem Scanning confocal microscope (Tandem Scanning Corp., Reston, VA). The densities obtained were compared with those obtained manually. This programme corrects the large nonuniformity in brightness across the acquired images by subtracting from each an image of a uniformly scattering standard solution. The measures of keratocyte density can be used in a variety of conditions, including contact lens wear, excimer laser keratorefractive surgery, and corneal transplantation.

The work presented in [7] describes a computer based approach to detect the keratocytes in stromal images aiming to provide accurate measurement of these cells and their spatial distribution in the cornea. These images were acquired from ultra-high resolution optical coherence tomography (UHR-OCT). This approach has