# INVIVO PATTERN RECOGNITION AND DIGITAL IMAGE ANALYSIS OF SHEAR STRESS DISTRIBUTION IN HUMAN EYE

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## ABSTRACT

*Human eye is made of a number of structural components to deliver vision, and cornea is the front window of the eye. Human cornea is made of soft biological materials. It is unfriendly for exposures to the common energy levels of X-ray scans for repeated probing of its structural architecture. Here we study an alternative imaging methodology by using a normal white-light source. By exploiting the natural birefringent property of cornea, the shear stress distribution pattern and its directional characteristics on the surface of cornea is recognized in vivo. Digital image processing of corneal retardation helps us to locate the stress concentration zones on its surface and to study their features along preferential directions. Such digital image outputs could be used in future to bench mark the health standard of cornea as well as a potential identity signature of people's eyes.*

## KEYWORDS

*Digital imaging, pattern recognition, cornea stress, eye strain*

## 1. INTRODUCTION

Medical imaging tools such as X-ray scanners, Magnetic resonance imaging (MRI), positron emission tracking (PET) and ultrasound scanners help us to detect and treat anomalies in human bodies [1]. A better eye sight is perhaps the most important factor influencing the quality of human life. Human eye comprises different transparent substances including cornea, the aqueous humour, the crystalline lens and the vitreous humour [2] Cornea resides at the front of the eye [2] as illustrated in Fig.1.

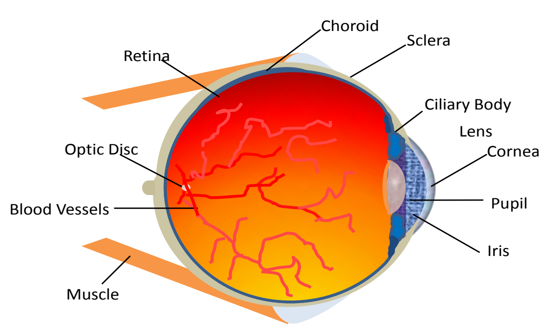



Figure 1: Schematic diagram of a human eye [3]

Previous studies on birefringent measurements in human eyes are mainlyfocused on the medical treatments Stress distribution in cornea could result due to the inherent molecular architecture of the corneal tissues [4,5] as well as contributed by the level of IOP in the eye (i.e, intra-ocular pressure measured conventionally as the average, stress microscopically is scarce in the literature. In a recent study [3], the author reported in vivo sensing of maximum shear stress distribution on human cornea using digital photo stress analysis tomography (PSAT). PSAT exploits the birefringent property of cornea tissues (Fig. 2). When a circularly polarised light from a normal white light source falls on the cornea, the out coming light is elliptically polarised [3]. Using an optical analyser, the light vectors of the elliptically polarised light at any point on the surface of the cornea can be characterised digitally (Fig.2). Using this information, the retardation of the light between the major and minor principal axis can be determined and related to the maximum shear stress using the stress-optic law [3].

Previous studies on the birefringence in human eyes focused on the medical treatments perspectives for example, to characterise retinal structures [7], their age effects [7] and in vitro analysis of keratoconus [8]. Using X-ray diffraction, some studies have shown diamond-like architecture of the collagen fibrils [9] which provides mechanical stability to the cornea [8]. However these studies are mostly in vitro as well as perhaps not suitable for repeated examinations of eye tissues. The shear stress patterns of cornea using PSAT had also correlated with the diamond-like architecture of the stress bearing fibril elements of the cornea [3].

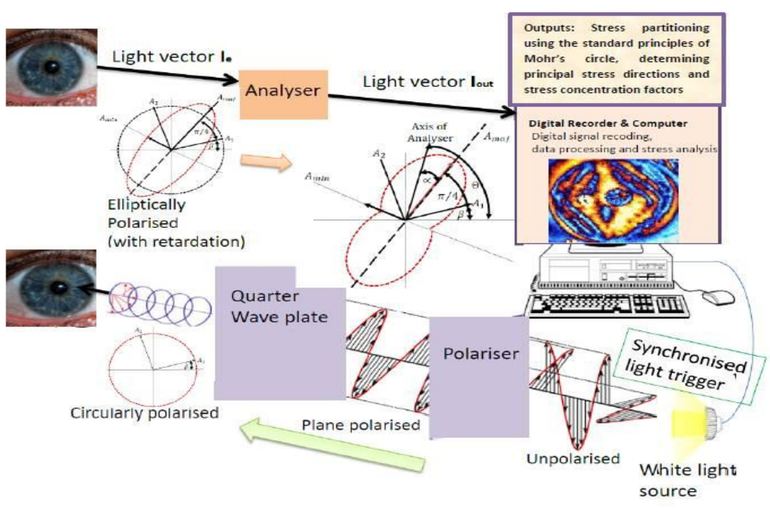



Figure 2: Schematic diagram of digital PSAT to recognise stress patterns in the eye [3]

## 2. Stress Distribution Characteritics Of Cornea As A Biomarker

The current study is the extension of our previous study [3] in which the shear stress concentration factors of a healthy human cornea in vivo were reported. For comprehensive details on the PSAT methodology and the partitioning of the stress components on cornea, the readers could refer to our previous work [3]. Here, we present some key features of the shear stress distribution characteristics (Fig.3, [10]) of a healthy cornea, and then digitally analyse for the direction of the major principal stress on its outer surface. We hope that such an analysis could potentially serve as a route map for bio marking the cornea in the individuals in future. Furthermore, bi-polar digital imaging scheme was applied to enhance the edge detection [11,12] of the stress bearing fibrils and this enhanced the visibility of diamond-like structure of the cornea fibrils.

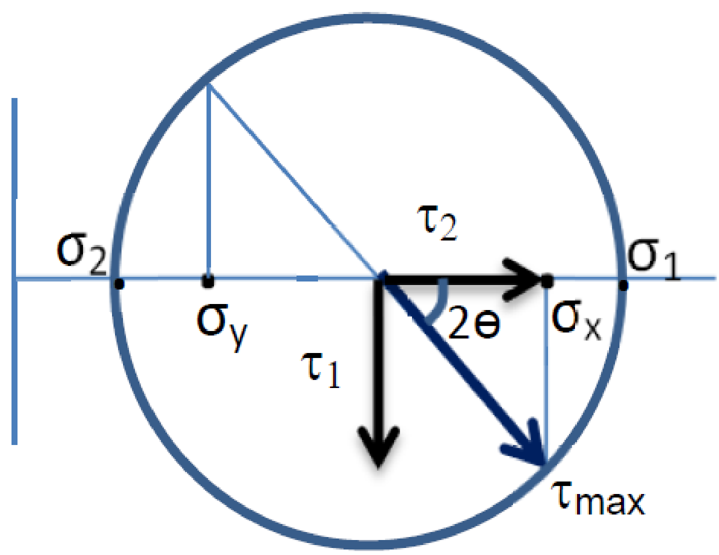



Figure 3: Partitioning of maximum shear $\tau_{max}$ at different planes using the principles of Mohr's circle [10]: $\tau_1$ represents shear stress acting in horizontal and vertical planes whereas $\tau_2$ represents shear stress acting at $45^{\circ}$ to the horizontal and vertical planes. $\tau_{max}$ acts at $45^{\circ}$ to the principal stress direction.

## 3. Results And Discussion

### 3.1 Diamond-like stress-bearing structure of cornea fibrils

Figure 4 shows the edge detection of the fibrils of cornea distributing the maximum shear stress. Here the output is presented in terms of the retardation of the light (which can be also converted to the Pa unit [3]).

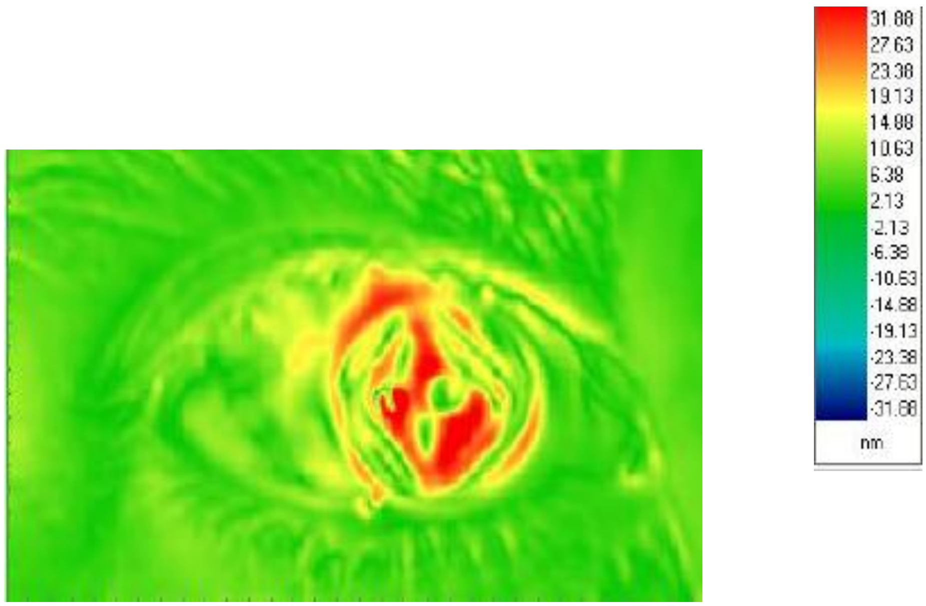



Figure 4: Diamond-like distribution of $\tau_{max}$along the horizontal (+ve) and vertical (-ve) planes on cornea.

The digital stress map presents a diamond-like structure similar to the structure displayed by X-ray scans of cornea in vitro [9]. However, it is worth noting that the current approach does not involve the use of any X-ray source. Hence the current approach could be more suitable for any repeated measurements of stresses in the cornea in future applications.

## 3.2 Identification Of The Feature Sof Maximum Principal Stress Along The Major Diagonal Axis Of The Corneaal Diamond

In Figure 5, the axes of the diamond structure are illustrated for the purpose of digital analysis of its mechanical characteristics in the following sections.

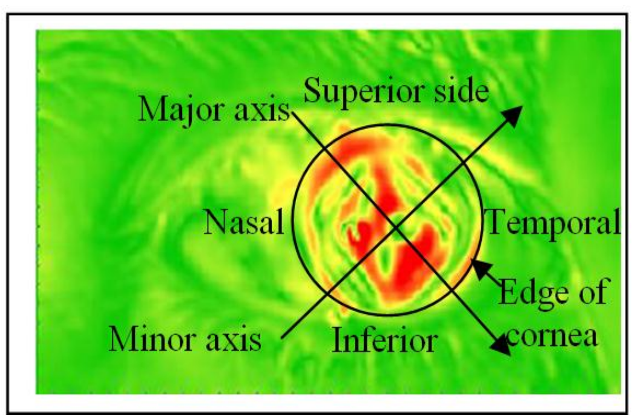



Figure 5: Illustration of the major and minor elliptical axes of the cornea diamond-like structure shown in Fig.4 and the anatomical terminologies.

From the digital information of the light r etardation discussed above, further analysis is performed to get the signature of the cornea by plotting the direction of major principal stress along the major axis of the 'corneal diamond'. This result is presented in Fig.6a, exhibiting equal numbers of three troughs (+ve degree) and crests (-ve degree) with well-defined spacing.

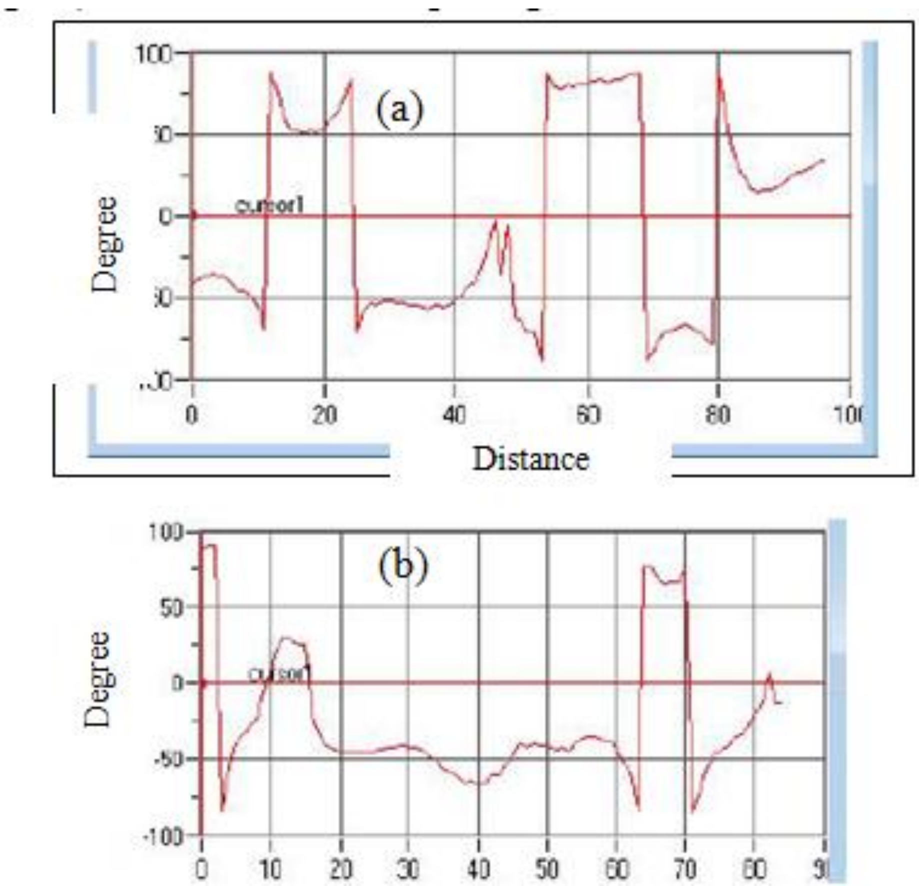



Figure 6: Variation of the direction of major principal stress along (a) major and (b) minor axes of the corneal diamond within the edges of the cornea

This information along the minor axis (Fig.6b) results unequal lengths of troughs and crests, and more dominantly with longer troughs along the middle region of the cornea. Hence along the minor axis, the direction of the major principal stress acts mostly along the vertical plane whereas along the major axis, the maximum shear stress is distributed along the horizontal and vertical planes periodically. Hence the distinctive features of this signature along the major axis can be studied in future, for example the spacing and width of the troughs and crests in relation to the angle of major principal stress as a signature of cornea in different individuals. For completeness, the maps of the direction of the major and minor principal stresses on the surface of cornea are presented in Fig.7.

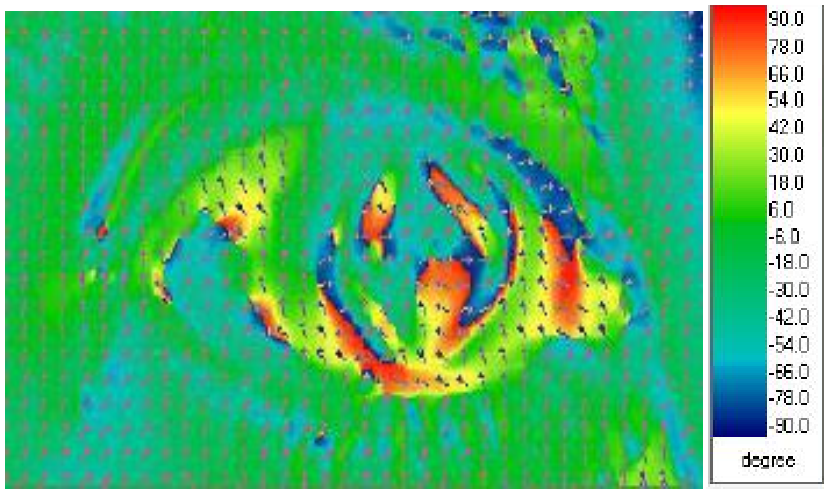
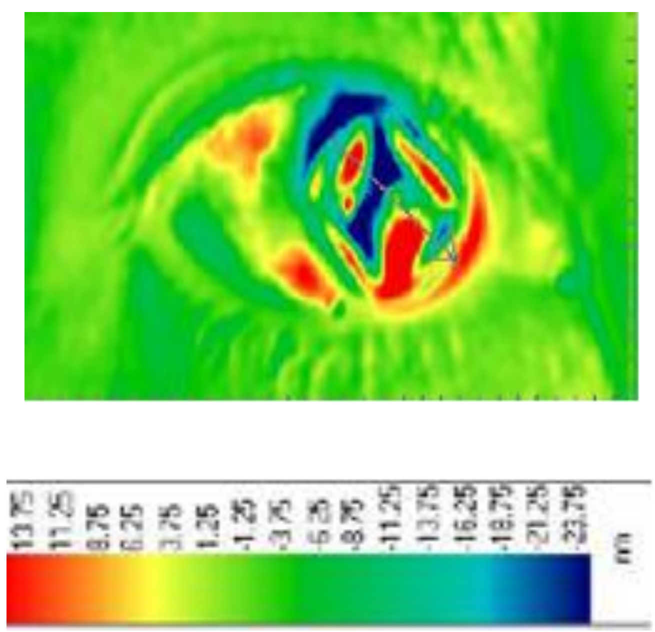


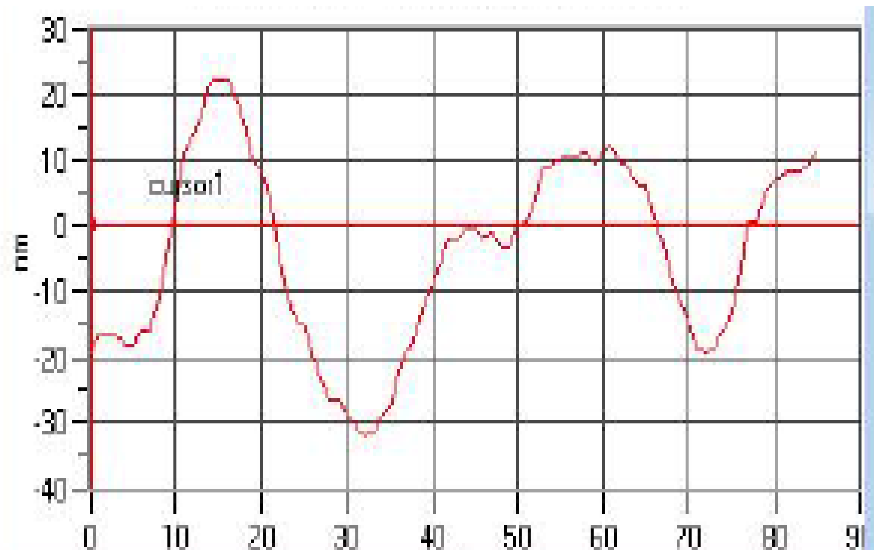

Figure 7: Major principal stress distribution is colour coded and the arrows show the direction of the minor principal stress on the cornea

### 3.3 Distribution of shear stress acting along the horizontal and vertical planes of cornea

Similar to Fig.6, the distribution of shear stress along the horizontal (+ve) and vertical (-ve) planes of the cornea are presented in Fig.8. In this plot, the digital information of these along the major principal axes of the diamond-like part of the cornea are also extracted from the retardation measures and quantified.




(a)




Distance

(b)

Figure 8: (a) Distrubtion of shear stress acting along the horizontal and vertical planes on cornea and (b) their quantification along the major axis of the corneal diamond as marked by the arrow in (a).

## 4. Conclusion

The stress distribution patterns on a healthy cornea of human eye are reported here using PSAT. The method senses the retardation of the light components between the major and minor optical axes at any point of interests on the surface of cornea. This information is digitally stored and a subsequently stress analysis is performed in detail. The bi-polar image enhancement clearly reveals a diamond-like stress distribution pattern on the surface of cornea. Previous structural studies of cornea using X-ray scans in vitro have shown such diamond-like structures. Based on the features of stress distribution, the current non-X ray based sensing provided an alternative way of bio-marking the cornea using ordinary white light source.


## Acknowledgement

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## REFERENCES


[1] P. Suetens, Fundamentals of medical imaging, Cambridge press, London, 2009.

[2] M. Millodot, Dictionary of optometry and visual science, Butterworth-Heinemann, London, 2009.

[3] S. J. Antony, "Imaging shear stress distribution and evaluating the stress concentration factor of the human eye", Scientific Reports,Nature Publishing Group, vol. 5, 8899, 2015,DOI:10.1038/srep08899

[4] J. Last, S. Thomasy, C. Croasdale, P. Russell and C. Murphy, "Compliance profile of the human cornea as measured by atomic force microscopy", Micron, vol. 43, 2012, pp.1293–1298

[5] K.M. Meek and N.J. Fullwood, "Corneal and scleral collagens-a microscopist's perspective", Micron 32, 2001, 261–272

[6] J. Jorge, J. Gonza´lez-Me´ijome, A. Queiro´s, P. Fernandes and M. Parafita, "Correlations between corneal biomechanical properties measured with the ocular response analyzer and ICare rebound tonometry", Jl. Glaucom., vol. 17, 2008, pp. 442-448.

[7] D. VanNasdale, A. Elsner, T. Hobbs and S. Burns, "Foveal phase retardation changes associated with normal aging", Vis. Res., vol. 51,2011,2263–2272

[8] E. Go¨tzinger et al, "Imaging of birefringent properties of keratoconus corneas by polarization-sensitive optical Coherence Tomography", Invest. Ophthalmol. Vis. Sci., vol. 48, 2007, 3551-3558.

[9] Boote, C., Dennis, S., Huang, Y., Quantock, A., and Meek, K.M. Lamellar orientation in human cornea in relation to mechanical properties. Jl. Struc. Biol., vol. 149, 2005, pp. 1–6.

[10] S.P. Timoshenko and J.N. Goodier, Theory of elasticity, McGraw-Hill, Singapore,1982.

[11] W. T. Rhodes, "Bipolar point spread function synthesis by phaseswitching," Appl. Opt.vol. 16, 1977, pp 265–267.

[12] B. Therese and S. Sundravadevelu, "Bipolar ioncoherent image processing for edge detection of medical images", Int.Jl. Recent Trends in Eng., Vol.2, 2009, pp. 229-232.