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# Poly-dimethylsiloxane (PDMS) an ideal biomaterial for cornea replacement

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**Abstract:**When the optical properties of the corneal is lost due to varieties of disorders, different procedures are applied so as to restore vision that can be reshaping the cornea, transplanting from a deceased donor or replacing the damaged cornea by synthetic ones (keratoprostheses). Currently, there are different materials used for keratoprostheses, however, this paper presents a new biomaterial for cornea replacement. It begins by looking in to the brief anatomy of the cornea followed by explanation of its biomechanical properties. After dictating the optical properties of the cornea, the paper elaborates associated diseases and disorders. It also suggests a suitable novel biomaterial and finally concludes that due to its good optical transparency and tunable refractive index, nontoxicity and biocompatibility, high gas permeability and good tensile strength PDMS can be an ideal biomaterial for cornea replacement.
**Keywords:** *Cornea, Biomaterial, PDMS, optical property, diseases of the cornea*

## I. INTRODUCTION

Quoted from Wikipedia, “the cornea is the transparent front part of the eye that covers the iris, pupil, and anterior chamber” [2]. Being the protective coat of the globe, collagen is the primary structural component of the hydrated cornea from which 90% of the collagen is found in the corneal stroma [12].

The human cornea is composed of six layers. The corneal epithelium is the outer most layer of the cornea. It is a fast growing multicellular tissue. The anterior limiting membrane, the Bowman’s layer protects the inner most and thick transparent corneal layer called stroma (substantia propria). Both Bowman’s layer and corneal strom are composed of mainly type I collagen. The fourth layer, Dua’s layer is thin, strong and able to with stand up to two bars of pressure and a newly discovered layer, which needs further study for confirmation. The posterior limiting membrane, Descemet's membrane is composed of mainly collagen type IV; hence, Descemet’s membrane is less rigid than corneal stroma. The simple squamous or low cuboidal monolayer, corneal endothelium, is the inner most layer of the cornea [2, 7, 13, 15].

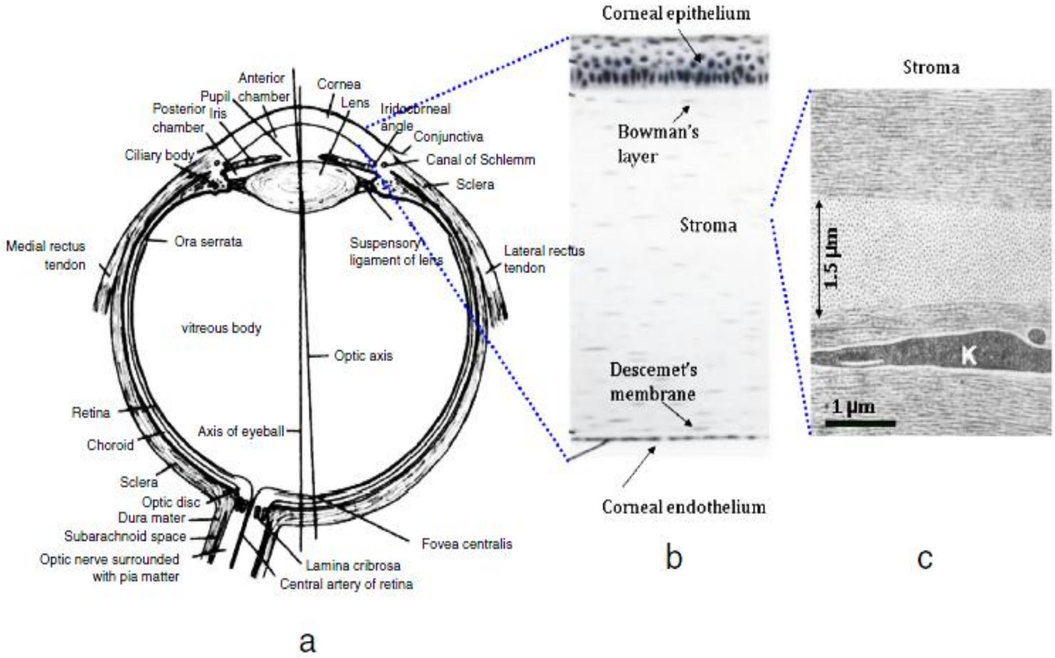


Figure 1: (a) Cross-section of the human eye. (b) Expanded view of the cornea showing the five layers: epithelium, Bowman’s layer, stroma, Descemet’s membrane, and endothelium. (c) TEM image of the stroma in the cornea showing two preferred orientations of collagen fibrils in successive lamellae. K: Keratocytes [15].

## II. BIOMECHANICALPROPERTIES OF CORNEA

The primary structural component of cornea is collagen. Collagen is found mainly in the Bowman's layer and in the corneal stroma and it is the primary source of corneal tensile strength [20]. The highly organized small diameter collagen fibrils of the corneal stroma are braced by hydrophilic proteoglycan matrix, which maintains uniform inter-fibrillar spacing and draws water from the anterior chamber and pre-corneal tear film via the endothelium and epithelium respectively to keep the cornea hydrated at a constant level. The variation in hydration level of the cornea alters the inter-fibril spacing, which also alters the transparency of the cornea. The fluid pumps located at the corneal endothelium and epithelium are responsible for steady hydration of the cornea [12]. From material point of view, William J. Dupps and Wilson described cornea's property as "a complex anisotropic composite with non-linear elastic and viscoelastic properties. It is also highly heterogeneous in the central to peripheral, anterior to posterior and rotational dimensions" [20].

Microstructural scale X-ray diffraction studies on human corneal reported by Jeffrey W. Ruberti et al. depicts the directional dependency of the collagen fibrils which lies in a lobed pattern and exhibit preferred orientations fluctuating from orthogonal in the central cornea to circumferential in the peripheral cornea near the limbus [9].

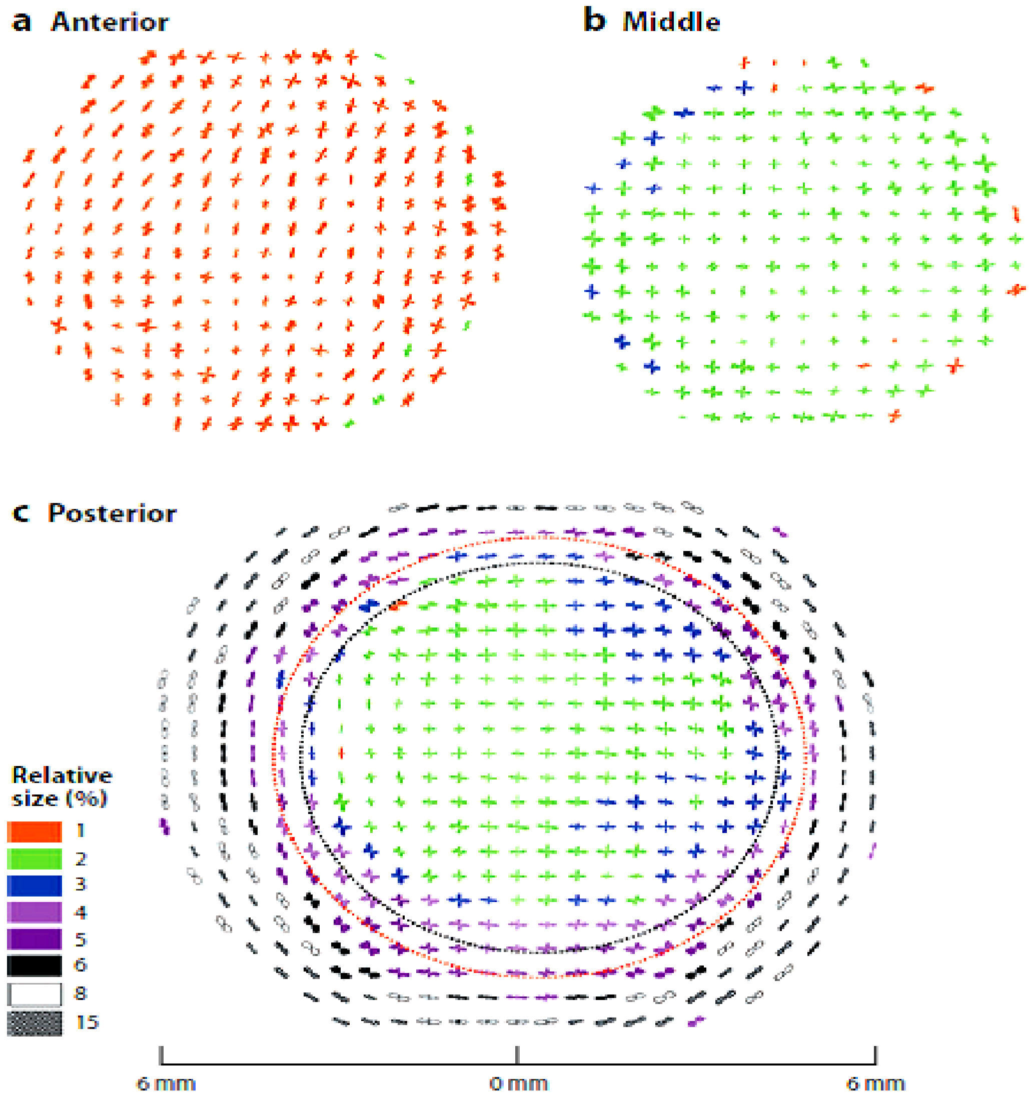


Figure 2: Organization of lamellae in the cornea as a function of depth: (a) anterior (one-third of the cornea), (b) middle (200–400 µm depth), and (c) posterior cornea (200 µm). Anterior cornea shows a random distribution, whereas the preferred direction is clearly seen in the posterior cornea. The relative size of the polar plots (as shown by the color key) is greater in the posterior layer than in the anterior and middle layers, indicating proportionally more aligned collagen in the posterior cornea [9].

Though unable to separate the corneal contributions to rigidity from scleral and uveal components, Friedenwald mentioned in William J. Dupps& Wilson, S. E. defined the ocular rigidity coefficient to measure the stiffness of the whole glob. This relationship is, nonlinearly related to intra-ocular pressure (IOP) and characterized by the slope of the pressure-volume curve (mmHg/mL) [20]. Additionally, hence the corneal strom contains approximately 80% water and due to the dynamic inter-fibrillar spacing capable of swelling under ex-vivo storage conditions, the cornea exhibits viscoelastic properties [9, 20].

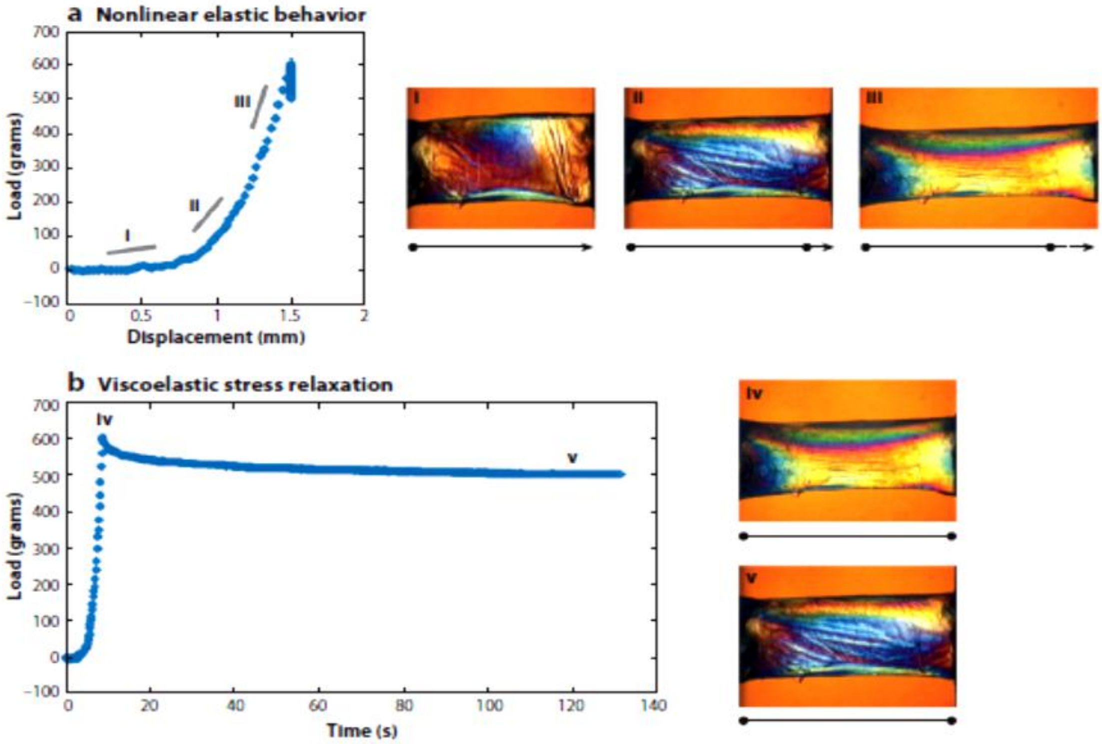


Figure 3: Elastic and viscoelastic stress testing of the cornea. (A) Stretching of the cornea (I-III) at a specific rate provides the load-versus displacement curve (elastic measurement). (B) The same sample when stretched by a certain length and released undergoes viscoelastic stress relaxation (IV, V). Elliptical polarization allows visualization of nonhomogeneous internal stresses. States I-V represent the corresponding loading states as seen in panels a and b [9].

## III. OPTICAL PROPERTIES OF THE CORNEA

Transparency being the prime function, there is no blood vessel in the cornea [19]. In the range of 400nm to 800nm wavelength, the cornea is almost transparent to light in free space [17]. Furthermore, though there are slight discrepancies in the literatures, the cornea contributes the majority of the refractive power of the eye (about 48 diopters) [14, 16, 19]. The refractive power of the cornea is mainly dependent on two important factors: corneal radii and refractive index. For many applications, the refractive power of the cornea is calculated assuming that the cornea is a homogenous optical body with refractive index of either 1.376 or 1.377 [18].

## IV. DISEASES AND DISORDERS OF THE CORNEA

Taken from Wikipedia, the following are the most common corneal disorders [2]:

- Corneal abrasion - a medical condition involving the loss of the surface epithelial layer of the eye's cornea because of trauma to the surface of the eye.
- Corneal dystrophy - a condition in which one or more parts of the cornea lose their normal clarity due to a buildup of cloudy material.
- Corneal ulcer - an inflammatory or infective condition of the cornea involving disruption of its epithelial layer with involvement of the corneal stroma.
- Corneal neovascularization - excessive ingrowth of blood vessels from the limbal vascular plexus into the cornea, caused by deprivation of oxygen from the air.

- Fuchs' dystrophy - cloudy morning vision.
- Keratitis - inflammation of the cornea.
- Keratoconus - a degenerative disease, the cornea thins and changes shape to be more like a cone.

## V. PROPOSED BIOMATERIAL FOR CORNEA REPLACEMENT

According to the World Health Organization, diseases of the cornea are a major cause of vision loss next to cataract [6]. In this regard, if a disease or disorder of the cornea happens, one of the many ways used to regain vision is by using kerato-prostheses (full thickness penetration of the cornea) or intra-corneal (partial corneal replacement) implants [4].

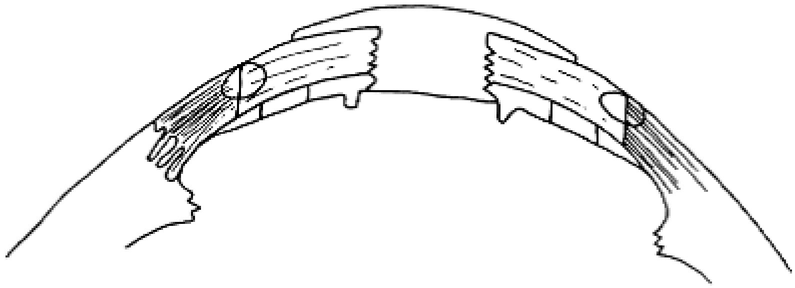

Figure 4: Schematic diagram showing a kerato-prosthesis implanted in the cornea [4].

Considering the functional role of the cornea, the main corneal implant design requirements include protection, transparency, and formation of a nearly perfect optical interface [9]. Additionally biocompatibility, integration, resistance against infection, oxygen permeability and longevity are important factors worth to be considered for a successful kerato-prosthesis. Currently there are varieties of biomaterials like PMMA, hydroxy-apatite, expanded PTFE and hydrogel that are used for production of Kerato-prosthesis [5, 9]. This paper, however, introduces a new suitable biomaterial:polysiloxane polymer (Poly-dimethylsiloxane-PDMS), for corneal replacement.

## VI. WHY POLY-DIMETHYLSILOXANE (PDMS)?

The following are the important properties of PDMS that makes it a suitable perfect biomaterial for cornea replacement:

- High gas permeability [21].
- Good optical transparency and tunable refractive index [21, 11]
- Non-toxicity and biocompatibility [21].
- Good tensile strength [3].

The average refractive index of PDMS varies from 1.4 to 1.54. Most of the time, the mean refractive index of the cornea is assumed to be 1.37; hence introduction of fluorinated groups will lower the refractive index of PDMS below 1.4. On the other hand, two possible methods can be used to increase the integration of the corneal prosthesis. The first method is to increase porosity of the implant to allow tissue ingrowth, promote transmission of nutrients and thereby preventing implant necrosis as well as lipid deposits [8]. The second option is to use specific sequence growth factor protein imprinted PDMS that enables the surrounding natural cells to inhabit the surface of the corneal margin (Hydrophobic Material Enables Development of Artificial [1, 10].

## VII. PATENTSEARCH

Searching from http://patft.uspto.gov/, 38 related patents were found. However, PDMS is used for intra ocular lens, contact lens, corneal onlay and corneal epithelial pocket formation systems, none of them use PDMS as a cornea implant. On the other website, http://www.epo.org/searching/free/espacenet.html, no match was found for PDMS as corneal implant biomaterial.

## VIII. CONCLUSION

To sum up, the cornea is the transparent front part of the eye that covers the iris, pupil, and anterior chamber. The primary structural component of cornea is collagen. Collagen is found mainly in the Bowman’s layer and in the corneal stroma and it is the primary source of corneal tensile strength. In the terminology of material science, cornea is a complex anisotropic composite with non-linear elastic and viscoelastic properties.

It is also highly heterogeneous in the central to peripheral, anterior to posterior and rotational dimensions. Transparency being the prime function, the cornea contributes the majority of the refractive power of the eye.

On the other hand, if a disease or disorder of the cornea happens, one of the many ways used to regain vision is by using kerato-prostheses (full thickness penetration of the cornea) or intra-corneal (partial corneal replacement) implants. Due to its good optical transparency and tune-able refractive index, nontoxicity and biocompatibility, high gas permeability and good tensile strength PDMS can be an ideal biomaterial for cornea replacement.

## References

[1]. 2010, *Hydrophobic Material Enables Development of Artificial Cornea* [Online]. Last Updated 25, May 2010 Available: http://medtechinsider.com/archives/14736 [Accessed October 21, 2013 2013].

[2]. 2013, *Cornea* [Online]. Wikipedia, Last Updated 15, October 2013, Available: http://en.wikipedia.org/wiki/Cornea [Accessed 18, October 2013].

[3]. Alvaro Mata, Aaron J. Fleischman & Roy, S., 2005, 'Characterization of Polydimethylsiloxane (PDMS) Properties for Biomedical MicroNanosystems'. *Biomedical Microdevices [Peer Reviewed Journal]* [Online], Vol. 7 (4), Available: http://download.springer.com/static/pdf/701/art%253A10.1007%252Fs10544-005-6070-2.pdf?auth66=1382704342_d3e8b41130163b38ebfa2cde6b61d819&ext=.pdf [Accessed 29, September 2013].

[4]. Andrew W. Lloyd, Richard G.A. Faragher & Denyer, S. P., 2001, 'Ocular biomaterials and implants '. *Journal of Biomaterials [Peer Reviewed Journal]* [Online], Vol. 22 (8), Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S0142961200002374/1-s2.0-S0142961200002374-main.pdf?_tid=40660574-2f08-11e3-99f1-00000aab0f02&acdnat=1381120003_52172a6593514beb245280bfe2c9bdf4 [Accessed 29, September 2013].

[5]. Christopher Liu, Bobby Paul, Radhika Tandon, Edward Lee, Ken Fong, Ioannis Mavrikakis, Jim Herold, Simon Thorp, Paul Brittain, Ian Francis, Colin Ferrett, Chris Hull, Andrew Lloyd, David Green, Valerie Franklin, Brian Tighe, Masahiko Fukuda & Hamada, S., n.d., 'The Osteo-Odonto-Keratoprosthesis (OOKP)'. *Seminars in Ophthalmology* [Online], Vol. Available: http://www.sjsupport.org/pdf/eye_info/Seminars_OOKP_PDF_5.05.pdf [Accessed 29, September 2013].

[6]. Derek Duan , Bettina J Klenkler & Sheardown, H., 2006, 'Progress in the development of a corneal replacement: keratoprostheses and tissue-engineered corneas '. *Expert Review of Medical Devices* [Online], Vol. 3 (1), Available: http://go.galegroup.com.ezproxy.flinders.edu.au/ps/retrieve.do?sgHitCountType=None&sort=RELEVANCE&inPS=true&prodId=EAIM&userGroupName=flinders&tabID=T002&searchId=R1&resultListType=RESULT_LIST&contentSegment=&searchType=AdvancedSearchForm&currentPosition=1&contentSet=GALE|A223872965&&docId=GALE|A223872965&docType=GALE&role=&docLevel=FULLTEXT [Accessed 20, October 2013].

[7]. Harminder S. Dua, Lana A. Faraj, Dalia G. Said, Trevor Gray & Lowe, J., 2013, 'Human Corneal Anatomy Redefined: A Novel Pre-Descemet's Layer (Dua's Layer)'. *Ophthalmology [Peer Reviewed Journal]* [Online], Vol. 120 (9), Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S0161642013000201/1-s2.0-S0161642013000201-main.pdf?_tid=e6089446-393b-11e3-9eaa-00000aab0f01&acdnat=1382241697_8dae309c63ba0eebd22a6d334536d01f [Accessed 19, October 2013].

[8]. Jean-Marc Legeais, Gilles Renard, Jean-Marie Parel, Olivia Derdarevic, Mei Mei-Mui & Pouliquen, Y., 1994, 'Expanded Fluorocarbon for Keratoprosthesis Cellular Ingrowth and Transparency '. *Experimental Eye Research [Peer Reviewed Journal]* [Online], Vol. 58 (1), Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S0014483584711936/1-s2.0-S0014483584711936-main.pdf?_tid=2f77e3e6-3b1e-11e3-853f-00000aacb361&acdnat=1382448838_d580c6204b5906f95199b3de3238f32a [Accessed 29, September 2013].

[9]. JeffreyW. Ruberti, Abhijit Sinha Roy & Roberts, C. J., 2011, 'Corneal Biomechanics and Biomaterials.(Report)'. *Annual Review of Biomedical Engineering [Peer Reviewed Journal]* [Online], Vol. 13 (27), Available: http://www.annualreviews.org.ezproxy.flinders.edu.au/doi/pdf/10.1146/annurev-bioeng-070909-105243 [Accessed 29, September 2013].

[10]. K. Lee, R.R. Itharaju & Puleo, D. A., 2007, 'Protein-imprinted polysiloxane scaffolds'. *Acta Biomaterialia [Peer Reviewed Journal]* [Online], Vol. 3 (4), Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S1742706107000177/1-s2.0-S1742706107000177-main.pdf?_tid=56887764-0236-11e3-adad-00000aab0f26&acdnat=1376191995_618ac93f89016a7714d593cd674b3e98 [Accessed 29, September 2013 ].

[11]. Kai Su, Jon V. DeGroot, Ann W. Norris & Lo, P. Y., 2005, 'Siloxane Materials for Optical Applications'. *Materials and Nanotechnologies* [Online], Vol. Available: http://lib.semi.ac.cn:8080/tsh/dzzy/wsqk/SPIE/vol6029/60291c.pdf [Accessed 29, September 2013].

[12]. Kotecha, A., 2007, 'What Biomechanical Properties of the Cornea Are Relevant for the Clinician? '. *Survey of Ophthalmology* [Online], Vol. 52 (2), Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S0039625707001816/1-s2.0-S0039625707001816-main.pdf?_tid=e9c5b748-28d9-11e3-aecb-00000aab0f6c&acdnat=1380440394_7c83f7868ec7864de9bf14657c204fba [Accessed 5 October, 2013].

[13]. Mª.D. Merindano, J. Costa, M. Canals, J.M. Potau & Ruano, D., 2002, 'A comparative study of Bowman's layer in some mammals: Relationships with other constituent corneal structures'. Vol. Available: http://www.eurjanat.com/data/pdf/eja.02030133.pdf [Accessed 19, October 2013].

[14]. Navarro, R., 2009, 'The Optical Design of the Human Eye: a Critical Review '. *Journal of Optometry* [Online], Vol. 2 (1), Available: http://apps.elsevier.es/watermark/ctl_servlet?_f=10&pident_articulo=13188759&pident_usuario=0&pcontactid=&pident_revista=310&ty=42&accion=L&origen=optometry&web=http://www.journalofoptometry.org&lan=en&fichero=310v02n01a13188759pdf001.pdf [Accessed 29, September 2013].

[15]. Raghu Ambekara, Kimani C. Toussaint Jr & Johnson, A. W., 2011, 'The effect of keratoconus on the structural, mechanical, and optical properties of the cornea'. *Journal of the Mechanical Behavior of Biomedical Materials* [Online], Vol. 4 (3), Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S1751616110001372/1-s2.0-S1751616110001372-main.pdf?_tid=e5859758-39f4-11e3-be13-00000aacb35f&acdnat=1382321153_c76f493f4e356b3adb2945c6c1b91937 [Accessed 19, October 2013].

[16]. Sicam, V. A. d. P. 2006, *Optical properties of the human cornea : Shape and wave aberration measurements using the VU topographer and Scheimpflug photography*, Advisor(s): Bouter, L. M., VRIJE UNIVERSITEIT, Available: http://dare.ubvu.vu.nl/bitstream/handle/1871/10864/ThesisSicam.pdf?sequence=2 [Accessed 19, October 2013].

[17]. Smith, T. B., 2007, 'Modelling corneal transparency'. *American Journal of Physics [Peer Reviewed Journal]* [Online], Vol. 75 (7), Available: http://scitation.aip.org.ezproxy.flinders.edu.au/docserver/fulltext/aapt/journal/ajp/75/7/1.2730840.pdf?expires=1382321686&id=id&accname=494219&checksum=8CCD0933C2162A11AD39AC0F7817129E [Accessed 19, October 2013].

[18]. Sudi Patel, John Marshall & Fitzke, F. W., 1995, 'Refractive index of the human corneal epithelium and stroma'. *Journal of Refractive Surgery [Peer Reviewed Journal]* [Online], Vol. 11 (2), Available: http://search.proquest.com.ezproxy.flinders.edu.au/docview/866990089?accountid=10910 [Accessed 29, September 2013].

[19]. Vo-Dinh, T. (ed.) 2003, *Biomedical Photonics Handbook*: CRC Press LLC. .

[20]. William J. Dupps & Wilson, S. E., 2006, 'Biomechanics and wound healing in the cornea '. *Experimental Eye Research* [Online], Vol. 83 Available: http://ac.els-cdn.com.ezproxy.flinders.edu.au/S0014483506001990/1-s2.0-S0014483506001990-main.pdf?_tid=8940fc78-28db-11e3-b2ff-00000aab0f6c&acdnat=1380441091_cba1bb0f34370ac3f59656646ff35df5 [Accessed 29, September 2013 ].

[21]. Xiujuan Zhang, Gui Lin, Sai R. Kumar & Mark, J. E., 2009, 'Hydrogels prepared from polysiloxane chains by end linking them with trifunctional silanes containing hydrophilic groups'. *Journal of Polymer* [Online], Vol. 50 (23), Available: http://www.sciencedirect.com/science/article/pii/S0032386109000457 [Accessed August 23, 2013].