

FEA Investigation of a Human Eye Model Subjected To Intra-Ocular Pressure (IOP) and External Pressure

V. V. Shukla

Department of Mechanical Engineering

Shri Ramdeobaba College of Engineering and Management,

Nagpur, M.S., India

Corresponding Author: *vivshukla@yahoo.com*

Abstract

The Finite Element Analysis presented in this investigation demonstrates the feasibility of employing an anatomically realistic finite element eye model with 8 components. 3-D model of the human eye which closely resembles the dimensions of the actual human eye was modeled in ANSYS®. The human eye is modelled as comprising of eight distinct regions, namely the cornea, the aqueous humor, the lens, the ciliary body, the iris, the vitreous humor, the choroid and the sclera. Intraocular pressure (IOP) is the pressure of fluid inside the eye. The average value of intraocular pressure within the human eye is 15.5 mmHg with fluctuations of about 2.75 mmHg. An increase in blood pressure is called hypertension similarly an increase in intraocular pressure is called ocular hypertension. An eye is considered to have ocular hypertension if intraocular pressure is consistently 21 mm Hg or above. In some typical physiological cases, a traumatic situation is reached when the eye is subjected to external pressure in addition to IOP. These typical cases are challenging and important for ophthalmologists. The stress distribution over all the eight components of the eye are presented and compared with multiple combinations of IOP and external pressure. The worst case has been observed at highest IOP and highest wind pressure situation yielding a highest stress of 29.883 kPa at the junction of sclera and cornea. This could be eliminated by proper precaution and utilization of protection gear operating in similar work conditions.

Keywords: *Human Eye Model, Intra-Ocular Pressure (IOP), Ocular hypertension,*

INTRODUCTION

Human eye reflects as well as refracts the light, even though it is a biomechanical structure. An eye has a pressurized, thick-walled complex bio-structure and fluid transport systems. Figure 1 shows the primary ocular structure of the human eye. The outer envelope of the eye is formed by two connective tissues, the cornea and sclera. The sclera is the white outer shell and principal load-bearing tissue of the eye as it sustains the intraocular pressure. The optic nerve is connected between the retina and the brain through the scleral canal. Light enters the eye through the cornea and traverses through the pupil, lens, and vitreous body before striking the retina. The lens is suspended by ligaments (the zonules) attached to the ciliary muscle [1-4]. Any alterations in these muscles cause the zonules to tug on the lens, so as to change lens shape and therefore focal length of the eye (accommodation). The ciliary body secretes a clear, colourless fluid called the aqueous humor. This fluid flows radially inward, bathing the lens, then flows through the pupil and nourish the cornea, before draining out of the eye it passes through the iris and cornea. This fluid flow is

responsible for creating a positive pressure within the eye, the so-called intraocular pressure (IOP), which has many interesting biomechanical consequences [5-8].

Additionally, the volume of vascular beds within the eye changes throughout the cardiac cycle, creating a time-varying component of the IOP in an effect known as the ocular pulse. The space behind the lens is filled with a relatively inert connective tissue called the vitreous body. It is quite porous and thus transmits the pressure from the anterior chamber throughout the interior of the eye.

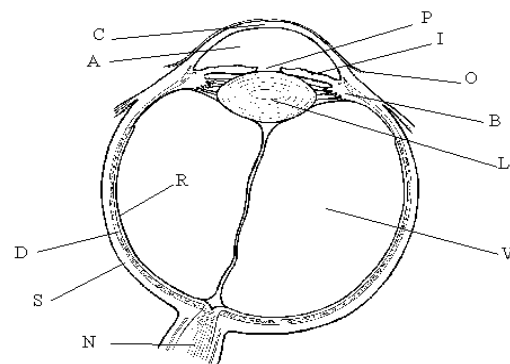


Figure 1: Primary ocular structures: A = anterior chamber, B = ciliary body, C = cornea, D = choroid, I = iris, L = lens, N = optic nerve, O = conjunctiva, P = pupil, R = retina, S = sclera, V = vitreous humor

Intraocular pressure (IOP) is the fluid pressure inside the eye. IOP is an important

aspect in the evaluation of patients at risk from eye disorders and abnormality. Current consensus among ophthalmologists and optometrists define normal intraocular pressure as that between 10 mm of Hg and 20 mm of Hg [9-10]. The average value of intraocular pressure within the human eye is 15.5 mmHg with fluctuations of about 2.75 mmHg. An increase in blood pressure is called hypertension similarly an increase in intraocular pressure is called ocular hypertension. An eye is considered to have ocular hypertension if intraocular pressure is consistently 21 mm Hg or higher. Ocular hypertension is a risk factor for glaucoma, a disease that damages the optic nerve. It is known that patients with intraocular hypertension had a higher risk of developing open-angle glaucoma [11].

1.1.1.1 2. Materials and Methods

Modeling the nonlinear geometries in ANSYS® is a very tedious and time consuming task. A human eye model in SLDPRT format (i.e. solid works format) is obtained and the file format is converted using solid works into IGES format, supported by ANSYS. The model is found

to be comprised of only areas and no volumes are generated. Therefore, the corrected solid geometry is recreated to compensate data loss incorporating the solid volumes, as shown in the Figure 2.

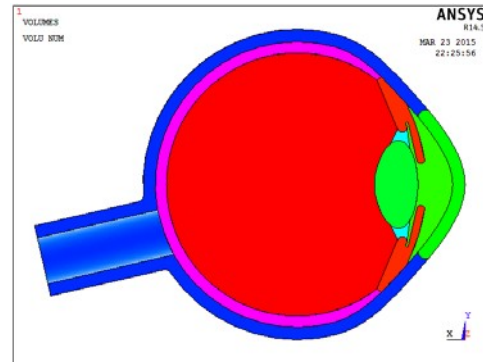


Figure 2: 3-D Solid geometric model of human eye

Thus, 3-D model of the human eye which closely resembles the dimensions of the actual human eye was modeled in ANSYS 14.5. Owing to the symmetric nature of the model for reducing the computational cost merely one half model of the eye is considered. The human eye is modeled as comprising of eight distinct regions, namely the cornea, the aqueous humor, the lens, the ciliary body, the iris, the vitreous humor, the choroid and the sclera. Figure 3 shows the exploded views of the components of human eye.

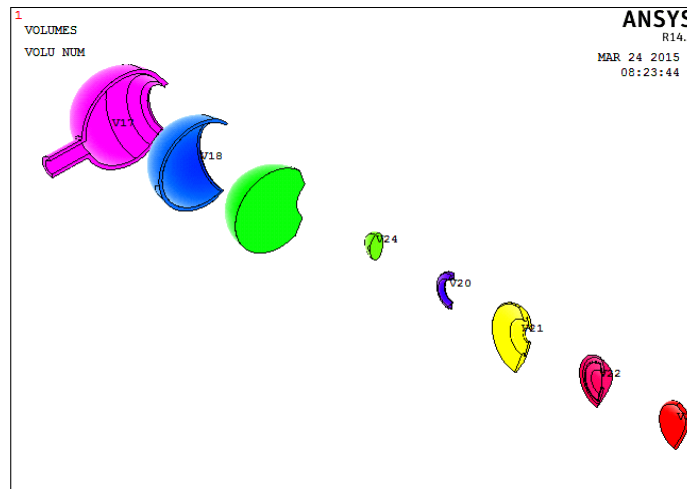


Figure 3: Exploded view showing all 8 components of eye model

Considering the effectiveness and utility, element type solid 185 is selected to mesh all the geometric components of the eye model. Tetrahedral free mesh of the complete eye model assembly is shown in Figure 4. Meshing of individual components of human eye is shown in Figure 5.

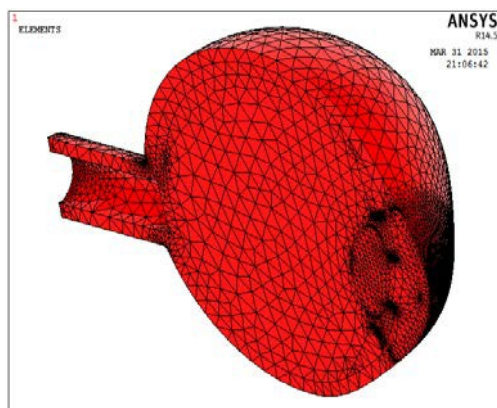


Figure 4: FE model of human eye with a free mesh of solid 185 elements

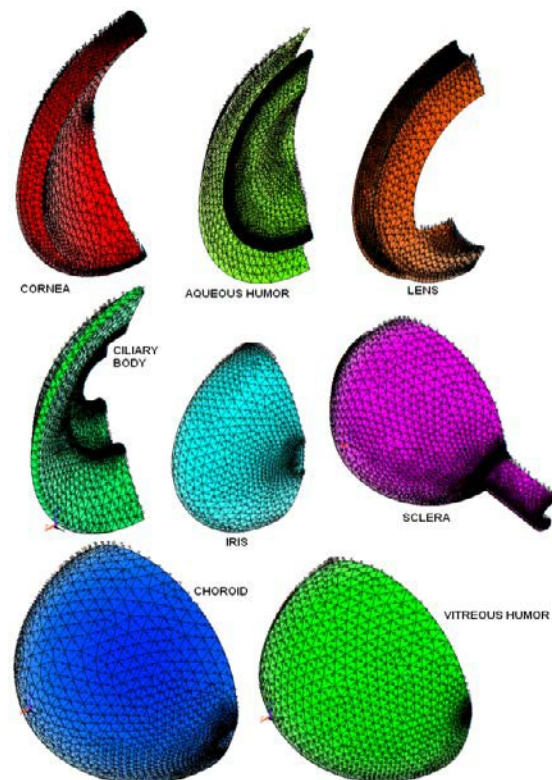


Table 1, presents the details of meshing of the eye model. Total of 499862 Element and

88322 Nodes are generated after meshing of the entire 3-D geometry of human eye.

Table 1: Mesh count for each volume/component

Sr. No.	Name of the Eye Component	ELEMENT COUNT	NODE COUNT
1	CORNEA	35278	8270
2	AQUEOUS HUMOR	119735	27858
3	IRIS	230265	46734
4	CILIARY BODY	22822	5651
5	LENS	19515	3984
6	VITREOUS HUMOR	30503	6343
7	CHOROID	7656	2370
8	SCLERA	34088	8460

Each region of the human eye is assumed to be homogeneous and isotropic. Structural properties such as Young's modulus of elasticity (E), density (ρ) and Poisson's ratio

(ν) are attributed to corresponding components of eye model, as listed in Table 2.

☐ for each

Table 2: Structural properties of each component of the human eye

Sr. No.	Name of the Eye Component	E (MPa)	ν	ρ (kg/m ³)
1	CORNEA	6.1 ^[2]	0.494 ^[2]	1400 ^[1]
2	AQUEOUS HUMOR	0.037 ^[1]	0.49 ^[1]	999 ^[1]
3	IRIS	0.5 ^[4]	0.49 ^[4]	1100 ^[3]
4	CILIARY BODY	11 ^[1]	0.4 ^[1]	1600 ^[1]
5	LENS	1.5 ^[4]	0.49 ^[4]	315 ^[1]
6	VITREOUS HUMOR	0.042 ^[1]	0.49 ^[1]	999 ^[1]
7	CHOROID	0.03 ^[4]	0.49 ^[4]	999
8	SCLERA	48 ^[2]	0.454 ^[2]	1400 ^[1]

The outer portion of sclera was fixed followed by application of symmetry boundary conditions over the areas of interest which defines the symmetry of the model. Finite Element Analysis for 6 combinations of external wind pressure and

IOP, as shown in Table 3, are carried out. The posterior chamber as well as the anterior chamber of the lens was applied with IOP and simultaneously the cornea was applied with wind pressure in successive load steps.

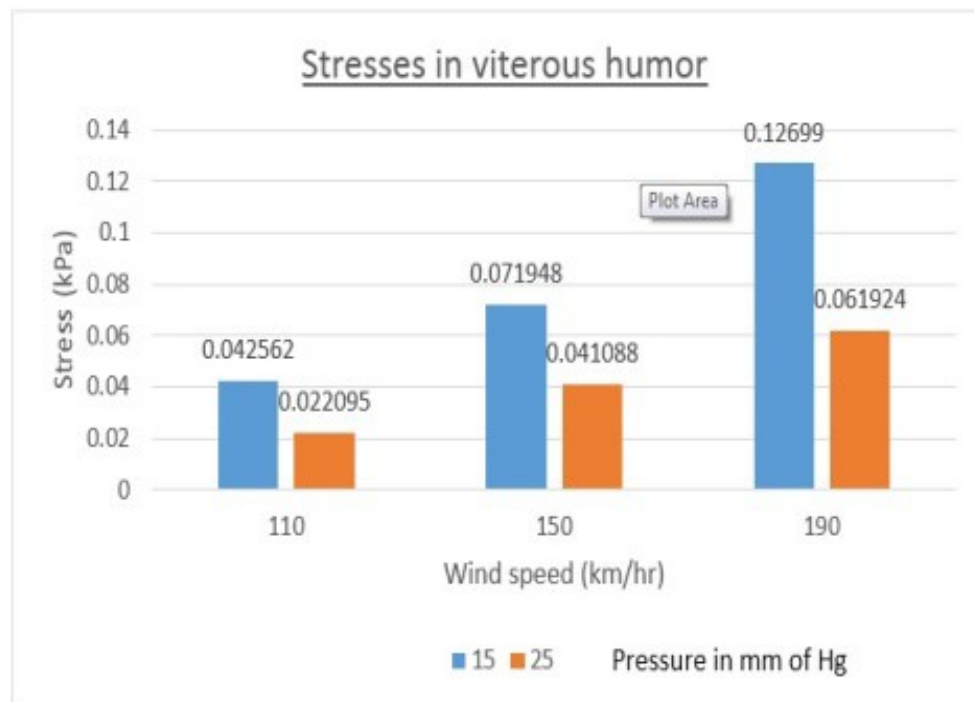
Table 3: Combination of IOP and External Wind Pressure for each load

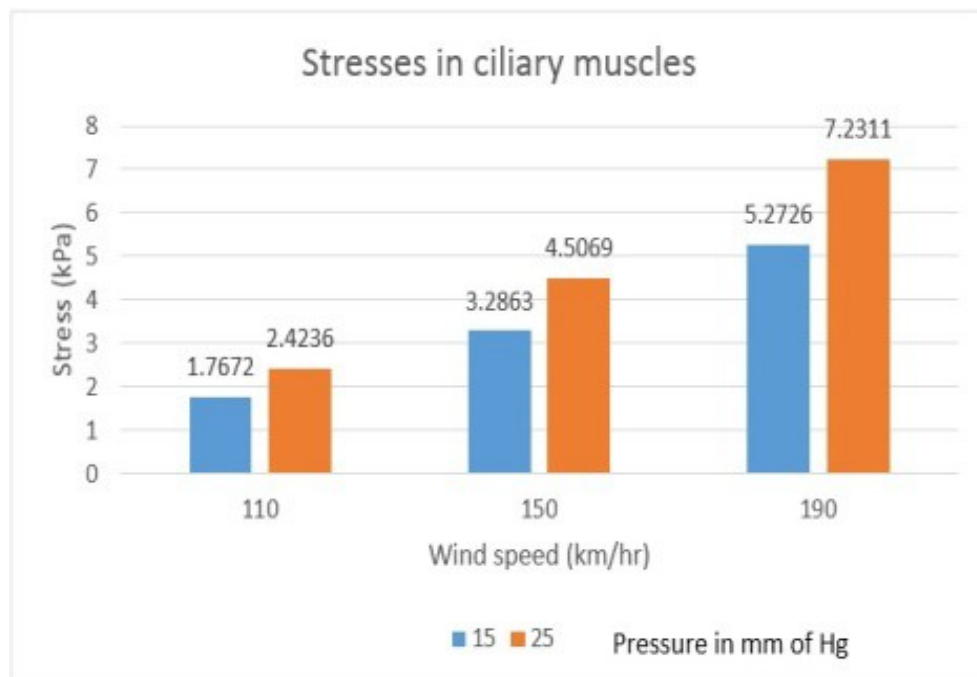
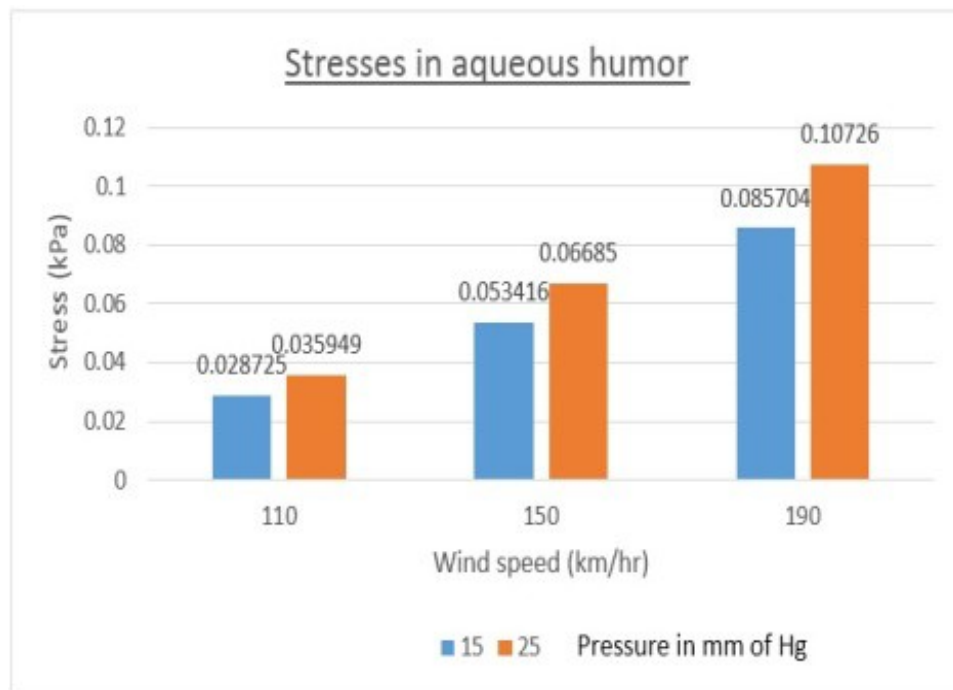
Sr. No.	Wind Velocity	Wind Pressure (N/mm ²)	IOP (N/mm ²)
1.	V= 110 km/hr	P = 5.5999e-4	(15 mm of Hg) = 2.0012e-3 (25 mm of Hg) = 3.335e-3
2.	V= 150 km/hr	P = 1.04135e-3	(15 mm of Hg) = 2.0012e-3 (25 mm of Hg) = 3.335e-3
3.	V= 190 km/hr	P = 1.67079e-3	(15 mm of Hg) = 2.0012e-3 (25 mm of Hg) = 3.335e-3

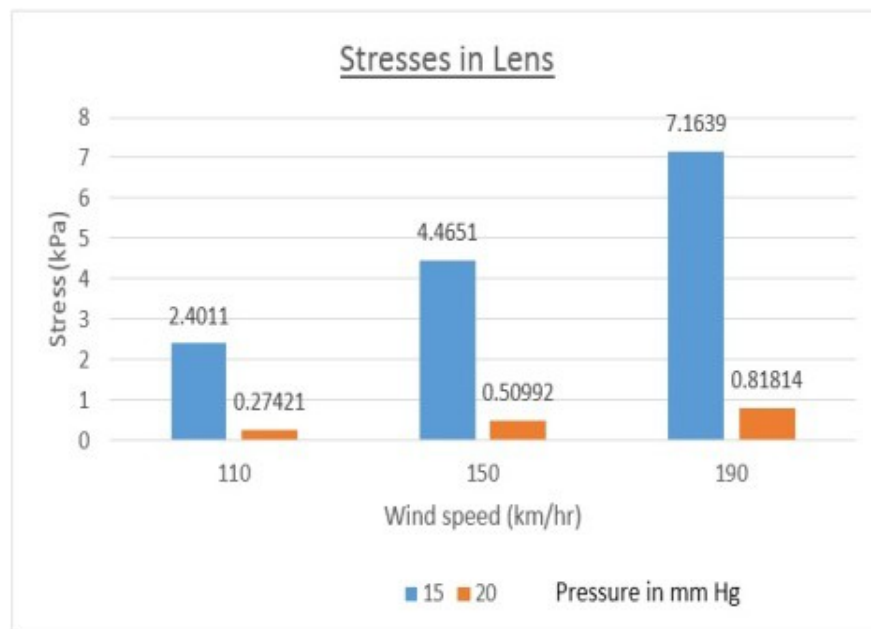
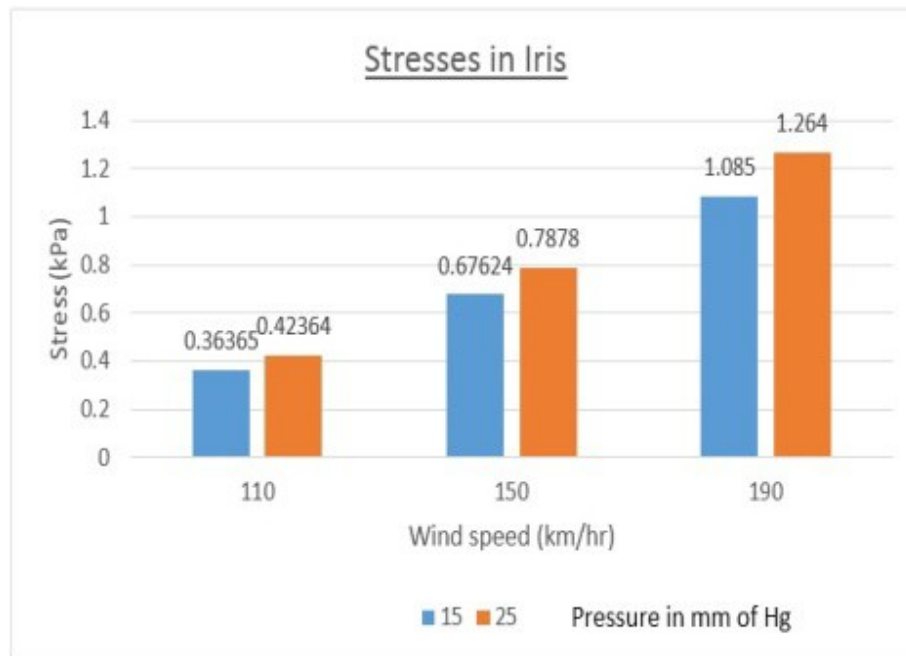
3. RESULTS AND DISCUSSION

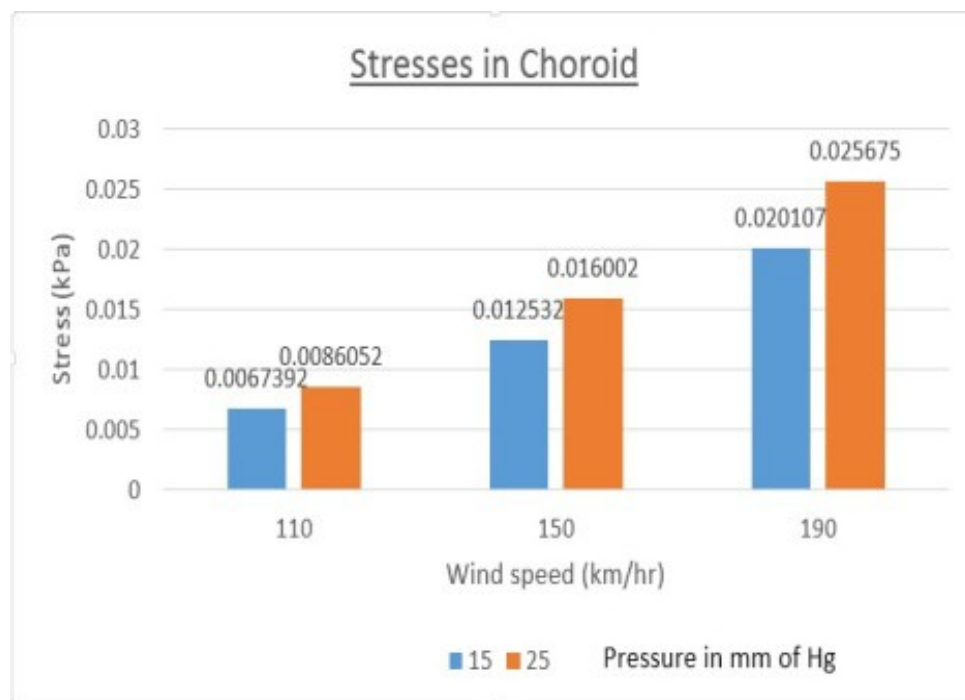
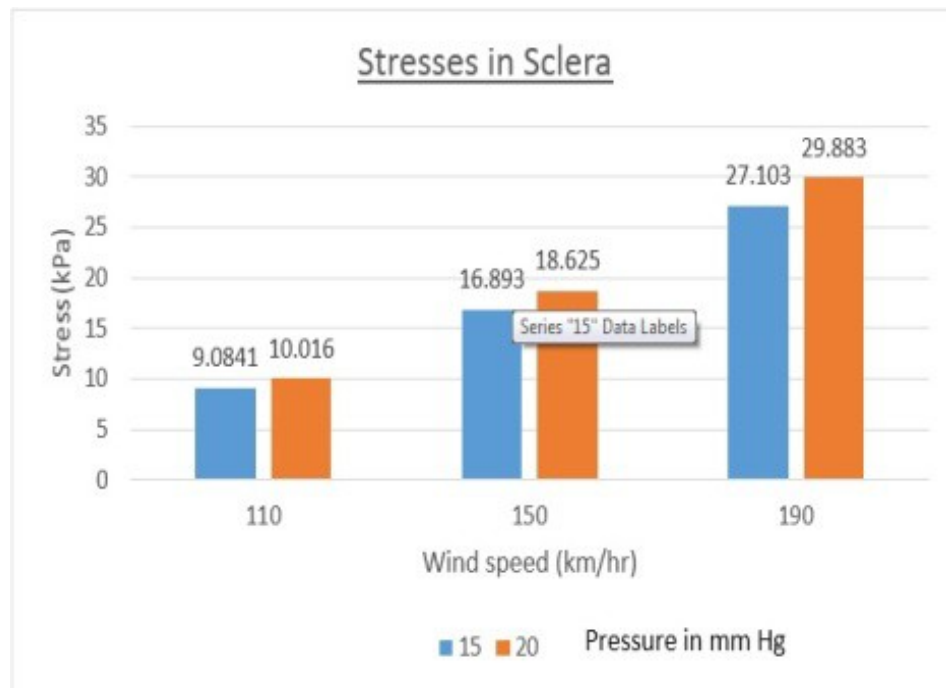
A robust and accurate Finite Element model is developed using the ANSYS 14.5 software. In this FE simulation, a model of the entire human eye including 8 components are analysed considering the simultaneous interaction of the various components of the eye under well defined boundary conditions. The ANSYS 14.5(R) software is used to model the eye because of the desired accuracy and robustness of the

model to provide accurate finite element simulation results. The inputs given to the GUI, which was developed for this model, are symmetry boundary condition, fixed nodal displacement on outer surface of the sclera, IOP in the anterior and posterior region of the lens with external wind pressure. Figure 6 shows the bar charts for numerically obtained stress on each component within the human eye.









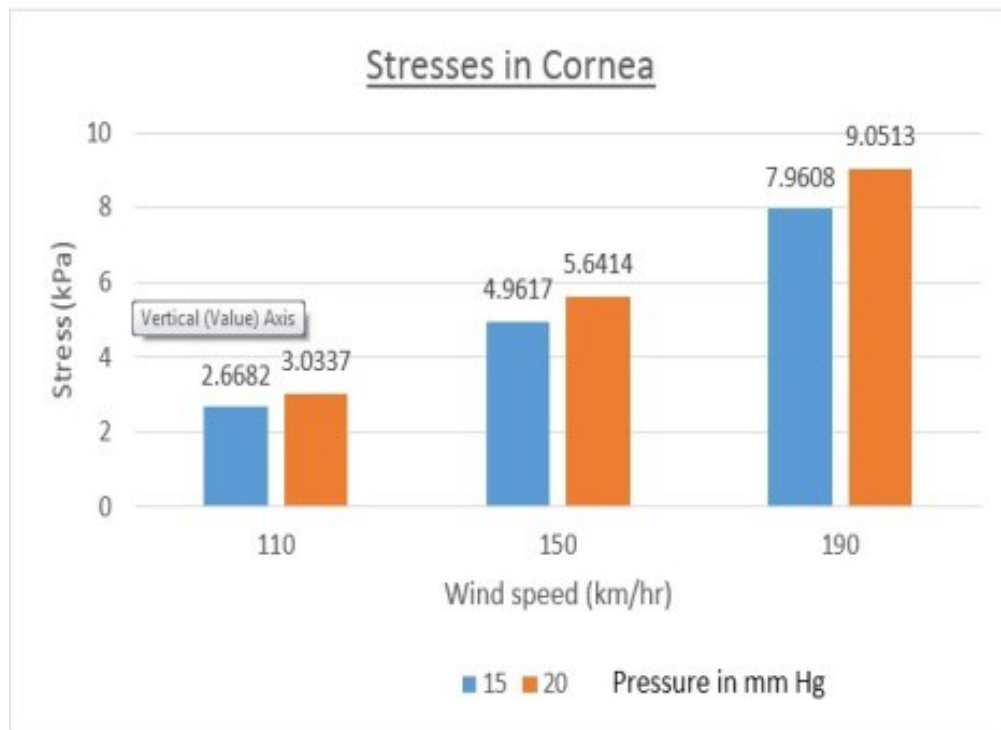


Figure 6: Comparison of the stresses on various components of human eye

Based upon the results from the study it is clear that all the components of human eye except vitreous humor and lens shows increase in stress level for increasing value of IOP i.e. approaching the stage of ocular hypertension as well as increased wind pressure. At the same time, increase in the displacements is also observed for increasing conditions of IOP and wind pressure. The highest stress of 29.883 kPa is observed on sclera volume for the IOP of 25 mm of Hg and 19 kmph wind speed.

CONCLUSION

Though there are a large number of computer models available of the human eye and various other parts of the body built for studying the impact trauma, physicians do not had the confidence to use these models for aiding in diagnosis in real life situations. The main reason for this is the vast computational load involved, taking hours for most of the simulations. Also, there seems to be lack of any major attempts taken by researchers to promote practical clinical usage of their models [12]. The most exciting future work for the study would be

in enhancing this current model simulation attributing non linear properties to a level of reliability that ophthalmologist can use it for predicting the extent of eye damages in real life situations. A rapid simulation using these inputs could provide an insight to design and develop the safety measures like head gears etc. to avoid potential extent of ocular injury. The worst case scenario has been observed at highest IOP and highest wind pressure situation yielding a highest stress of 29.883 kPa at the junction of sclera and cornea. This could be eliminated by proper precaution and utilization of protection gear operating in similar work conditions.

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