EVALUATION OF DIFFERENT PROJECTILES IN MATCHED EXPERIMENTAL EYE IMPACT SIMULATIONS

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INTRODUCTION

There are over 1.9 million eye injuries each year in the United States with trauma being the second leading cause of visual impairment [1]. Common sources of eye trauma include motor vehicle crashes, military operations, and sporting events. Experimental eye impacts and computational simulations with a variety of blunt objects have been used previously to determine injury tolerance of the eye. The VT-WFU Eye Model is a finite element model of the eye validated to predict globe rupture for dynamic blunt impacts and is used in this study to model eye impact experiments with a variety of projectiles and loading conditions [2].

METHODS

A collection of experimental eye impact tests in the literature were computationally modeled using an FE model of the eye to analyze global and localized responses to a variety of blunt projectile impacts [2,3,4]. Eight projectile geometries were simulated to recreate the experiments, including varying sizes of several geometries, for a total of 79 cases. The geometries, material properties, and impact velocities of projectiles modeled are summarized in Table 1. A separate FE model was created for each projectile and impacts were simulated in LS-Dyna (LSTC, Livermore, CA) with the existing eye model surrounded by a simulated orbit and soft tissue. Lagrangian and Eulerian meshes in the eye model allow for analysis of the mechanics of solid and fluid interactions. Peak pressure in the center of the vitreous and maximum principal stress in the corneoscleral shell and associated element location were computed for each case. Statistical analyses were performed to investigate the eye response.

RESULTS AND DISCUSSION

Based on previously published globe rupture levels (stress: 23 MPa, pressure: 2.1 MPa), the computational results agreed well with the experimental results. Mean stresses and pressures were significantly higher and exceeded the rupture thresholds in simulations matched to experiments where globe rupture occurred (Table 2).

Table 2: ANOVA comparison of computational simulations grouped by experimental globe rupture

Metric, MPa	**Rupture**		**No Rupture**		*F Ratio*	*P*
	Avg	*SD*	*Avg*	*SD*		
Stress	24.2	6.1	10.0	5.1	120.7	<0.0001
Pressure	2.2	0.8	0.5	0.5	122.1	<0.0001

Peak stresses were located in different regions of the eye for different projectiles (Figure 1). Peak stresses occurred in the cornea for the BB and in the limbus for the plastic, foam, and some aluminum rods. Other projectiles such as the baseball and paintball caused peak stresses near the equator due to equatorial expansion of the eye.

Relationships between peak stress and pressure and projectile geometry, velocity, kinetic energy (KE), and area-normalized KE were investigated. Normalized KE had the highest Pearson correlation coefficients (stress: 0.89, pressure: 0.66) and was found to be a much better predictor of peak stress and pressure than KE alone (Figure 2). This supports previous findings that normalized KE is a better predictor of globe rupture [4].

The remainder of the difference between the normalized kinetic energy and peak stress is likely explained by two things: the bluntness versus sharpness of the impactor and the relative size of the impactor versus the cross sectional area of the eye. A multiple regression analysis has shown incorporating the relative size of the projectile tightens the grouping of the stress response data.

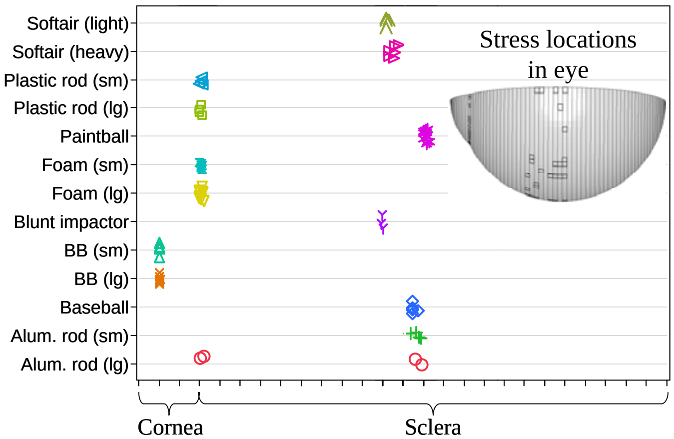

Figure 1: Locations of peak stresses in eye.

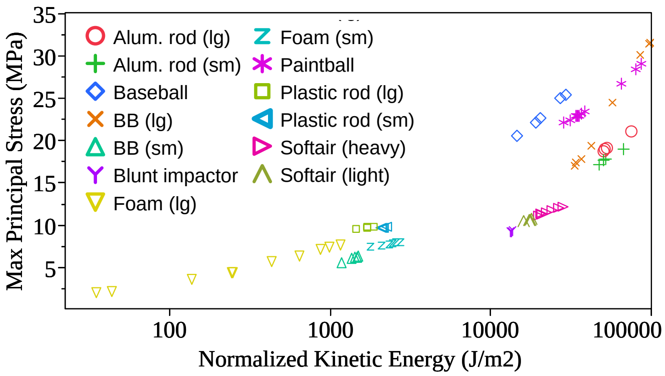

Figure 2: Area-normalized kinetic energy versus maximum principal stress for different projectiles.

CONCLUSIONS

This study determined the stress and pressure response of the eye through computational modeling of a variety of projectiles and loading conditions. Simulations predicted the region of the eye where injury is most likely to occur for a particular projectile. Normalized energy was highly correlated with peak stress and pressure and was the best single predictor of globe rupture. Incorporation of the projectile relative size reduced variability in the stress response and may be of importance in eye injury prediction.

In summary, the computational results agree strongly with the matched experimental results. This further validates the ability of the eye model to predict globe rupture in diverse loading conditions and scenarios and is of value in mitigating injury caused by blunt ocular trauma.

REFERENCES

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Table 1: Summary of Simulations

Object	# Cases	Dia. (mm)	Mass (g)	Modulus (N/mm^2)	Vel. Limits (m/s) Lower	Vel. Limits (m/s) Upper	Average Max. Stress (MPa)	Average Max. Pressure (MPa)
Baseball	5	76.10	146.50	12	30.10	42.80	23.13	2.18
BB, lg	9	4.50	0.38	200000	53.00	122.40	26.16	1.12
BB, sm	5	4.37	0.34	200000	10.18	11.47	6.01	0.11
Paintball	12	17.30	3.13	12	65.50	112.50	24.14	2.70
Softair Pellet, heavy	7	6.00	0.21	1800	73.03	87.35	11.62	0.75
Softair Pellet, light	4	6.00	0.12	1000	88.32	117.80	10.64	0.70
Aluminum Rod, lg	4	11.16	5.19	70000	43.71	53.21	19.49	1.82
Aluminum Rod, sm	4	9.25	3.57	70000	42.13	59.20	17.93	1.61
Blunt Impactor	3	19.90	112.55	3000	8.53	8.72	9.37	0.56
Foam, lg	12	6.35	0.08	2	4.30	31.00	5.04	0.13
Foam, sm	6	4.50	0.04	2	38.06	47.23	7.78	0.19
Plastic Rod, lg	4	9.75	0.69	1000	17.83	20.16	9.74	0.41
Plastic Rod, sm	4	7.62	0.35	1000	23.50	24.46	9.72	0.36
Total Runs	**79**							