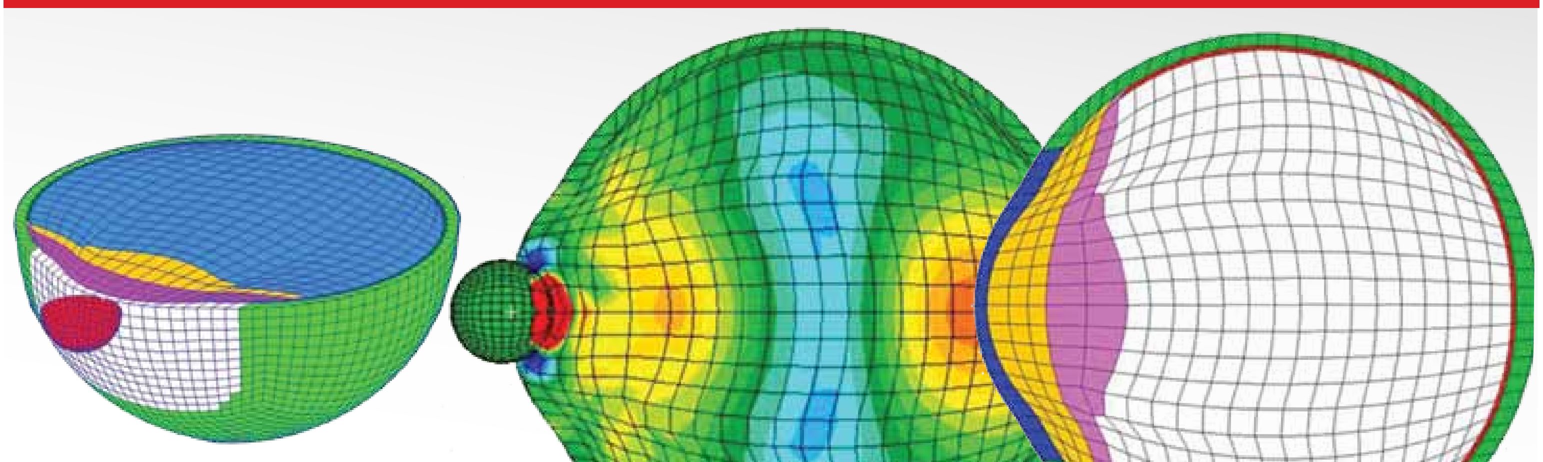
CASE STUDY

MSC Software: Case Study - University of Cassino

# Understanding Eye Injuries

## Simulation of the Mechanism of Retinal Detachment as a Result of Blunt Impact Trauma




### Summary

The detachment or tearing of the retina in the human eye as a result of a collision is a phenomenon that occurs very often. The project was aimed at understanding the actual processes of dynamic deformation taking place in the human eye when subjected to blunt impact. For this project an FEA model was developed in MSC's Dytran software starting from 3D measurements of real human eyes. The results of the model were then compared to measurements with respect to the deformation at different times and to the residual velocity of the projectile during the rebound phase.


### Introduction

Over 60% of all eye injuries are caused by blunt impact, i.e. impacts with objects of various kinds that do not cause a perforation of the globe. The clinical manifestations of such injuries is quite different and includes retinal rupture, choroid rupture (the tissue between the retina and the sclera), retinal tear and retinal detachment, macular holes and dialysis (see Figure 1 for the primary structures of the human eye).

Although the clinical phenomenology of such injuries has been accurately described already, the mechanisms responsible for the lesions of the retina and choroid associated with blunt impacts have not yet been fully understood. Among the theories proposed to explain the mechanism of damaging internal structures of the eye during a blunt impact, the most widely accepted one is called "vitreous chord pulling-traction". According to this theory, during the compression of the eyeball in the direction of the impac, the expansion of the sclera in the orthogonal direction generates a critical stress in the internal structures favored by the viscous

### Key Highlights:

**Industry**

Medical

University of Cassino

**Challenge**

To understand the cause of retinal detachment due to blunt impact trauma

**MSC Software Solutions**

Dytran

**Benefits**

- Increased Medical Understanding
- Practical Applications in the Military Field

**"Based on evidence of a patient, who, despite having undergone the removal of the vitreous, had a clear macular hole resulting from a blunt impact, it was decided to investigate this phenomenon to validate the various hypotheses of damaging mechanism with the help of MSC Dytran."**

Prof. Nicola Bonora, University of Cassino, Italy, Professor of Mechanical Design and Construction Machinery

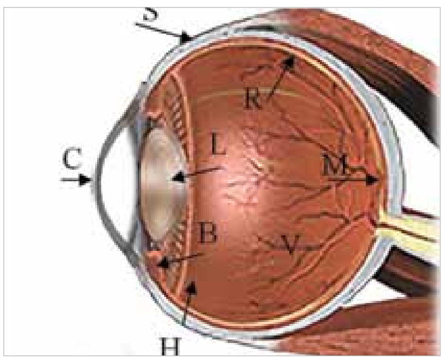



Figure 1: Primary structures of the human eye: C) cornea, S) sclera, L) crystal, R) retina B) ciliary body; M) macula, V) glassy, H) vitreous base.

action of the vitreous, the jelly-like fluid contained in the main eye socket. This mechanism would explain why the retinal tears occur mainly at the vitreous base, i.e. in the vicinity of the circumferential junction between retina and choroid and in the vicinity of the macula.

Based on evidence of a patient who, despite having undergone the removal of the vitreous, had a clear macular hole resulting from a blunt impact, it was decided to investigate this phenomenon in more detail in order to validate the various hypotheses of damaging mechanism with the help of a MSC Dytran simulation. In particular, the behavior of a human eye subjected to blunt impact as a result of impact with the ball of steel has been simulated. The model, validated through a comparison of the simulation results against measured data available in literature, was then used to study the intensity of the dynamic stress waves produced during the impact, in order to assess the primary source of retina failures.

## The Simulation Model

The computational model of the ocular globe was generated starting from an average size human eye represented with the help of the code MSC Dytran. The code was selected between the different explicit solvers available on the market mainly because of its advanced fluid-structure interaction capabilities. Assuming as symmetry plane the meridian section of the globe that contains the longitudinal axis, a half-eye model has been created that includes all substructures and tissues that could potentially affect its dynamic behavior: cornea, sclera, aqueous and vitreous humor, crystalline, ciliary body and zonules. The retina was modeled as a thin layer connected to the sclera with constant thickness of 0.2 mm. The related 3D mesh, shown in Figure 2, consisted of 6912 brick elements. The spherical projectile with a diameter of 4.5 mm was modeled as a rigid body. The configuration used for the simulations is that of a normal impact, in which the bullet hits the apex of the cornea in longitudinal direction at a speed of 62.5 m/s (Figure 3).

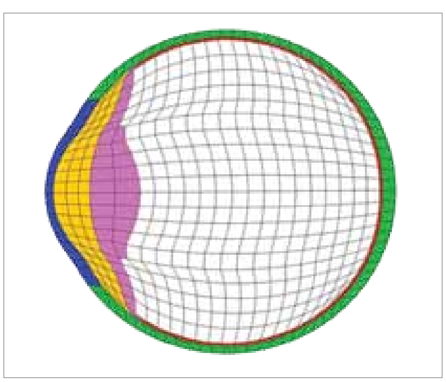


Figure 2: 3D mesh of the eye - each color identifies a different substructure.

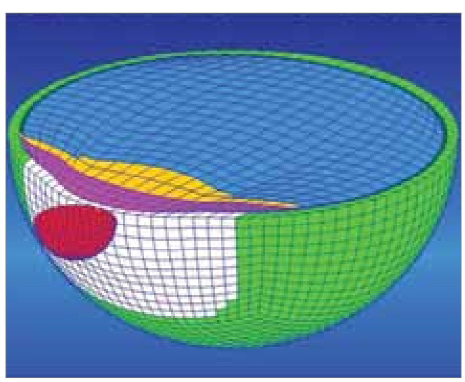


Figure 3: Layout of the simulated impact in longitudinal direction

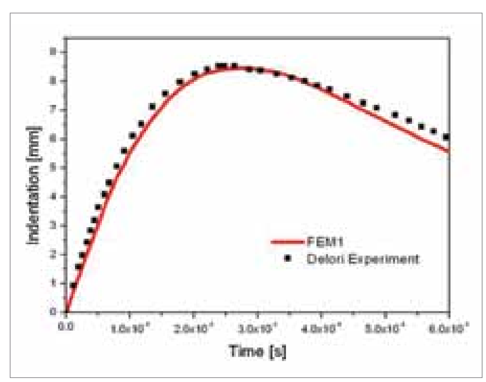



Figure 4: Comparison between the experimentally measured displacement and the numerical simulation.

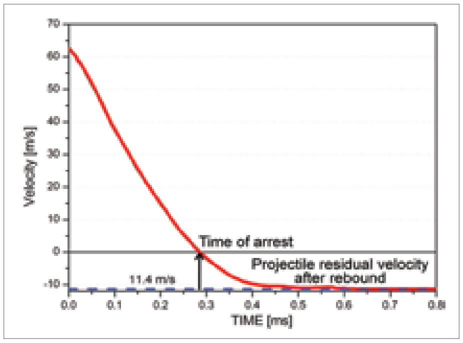



Figure 5: Evolution of the velocity of the projectile: comparison between arrest time and residual velocity of the projectile.

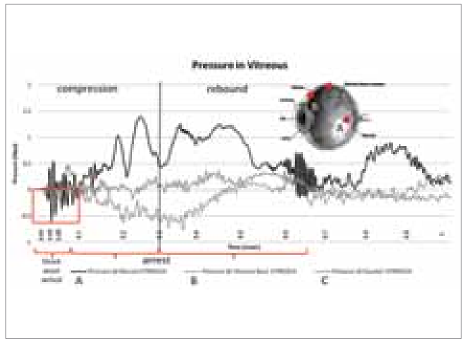



Figure 6: Evolution of pressure in three representative points in the macular area, the vitreous area and in the equatorial zone (negative pressure values represent traction).

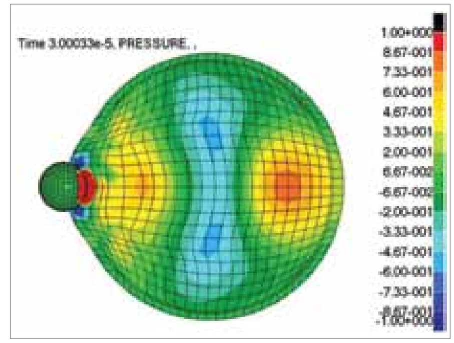



Figure 7: Propagation of waves of pressure in the ocular globe 0.03 milliseconds after the impact

## The Case in Exam

Given the complexity and variability of the physical and mechanical properties of all biological materials, that are strongly dependent i.e. by the hydration of the tissues and on how they are stimulated during the characterization tests, the related identification has been performed using the experimental results obtained by Deloria et al. in 1967 through a non-penetrating impact test of the human eye. In the present case, the experimental values of corneal apex displacement caused by the penetration of the projectile as a function of time have been used as reference.

Additionally, the methodological principle of “Occam’s Razor” has been adopted as constitutive model to describe the behavior of all tissues. This principle enables to minimize the number of parameters necessary to describe the phenomenon with the requested accuracy.

The description of the tissues is based on a linear elastic material model (that neglects all visco-elasto-plastic effects) and on linear state equations. The vitreous has been modeled with viscoelastic fluid with damping. Crystalline and choroid have been described through linear state equations. The model parameters have been then identified through a reverse calibration process that uses as objective function the experimental measurements produced by Deloria et al. Figures 4 and 5 show the experimental values compared with the optimized response of the numerical model.

## The Results

A careful examination of the results obtained through the simulation show that most of the retinal ruptures, which occur as a result of a blunt impact, are located in the macular and in the vitreous area, but very rarely affect the equatorial area. In order to fully understand the simulation results, the pressure values have been extracted in three points of interest. Figure 6 shows that the pressure waves, generated by the impact, propagate in the eye and are reflected as traction waves, thus affecting mainly the ocular fundus and the macula. The speed of propagation of the waves in the eye is much higher than the speed of the bullet, therefore the peak values of tensile pressure (about 0.6 MPa) were observed within 0.05 milliseconds after the impact when the ocular globe is not yet affected by large deformations (Figure 7). Shortly after the impact (at time = 0.1 milliseconds), the sclera starts to be affected by large deformations due to the penetration of the projectile. This causes the macular area to be subjected to compression, while the vitreous area is mainly subjected to traction. The pressure in the equatorial area is much lower than in other areas, and this confirms that there is a lower risk of rupture of that portion of the retina.

## Conclusions and Future Developments

The preliminary results of the project indicate that the laceration of the retina mainly occurs due to the tension resulting from the reflection of compression waves in the moments immediately following the impact, and not necessarily due to the deformation of the whole eye. The availability of a reliable and validated model for the simulation enabled the research team to understand in detail the pathogenesis of the blunt impact phenomenon, which is particularly difficult to reproduce in a controlled and instrumented manner through physical tests in the laboratory. Practical applications of this study are to be found especially in the military industry, for example in the design of advanced security systems for personnel and for helicopter pilots in the event of a crash landing.

## About University of Cassino, Italy

The University of Cassino was founded in 1979 and - due to its geographical location - it occupies a strategic location between all main cities in Central Italy. The University is composed by five faculties: Economics, Engineering, Humanities, Law, Physical Education and counts 12,000 students and 336 professors and researchers distributed in 7 departments with 47 laboratories. The students can choose between 18 undergraduate programs, 14 master degree programs and 8 doctoral programs. The infrastructure of the University also offer sports facilities that support the activities of the Faculty of Sport Sciences. The University has a strong international presence both in terms of research and educational activities: in fact, the Faculty of Economics of the University recently initiated the first undergraduate course in English language dedicated to Global economy and business.

## About MSC Software

MSC Software is one of the ten original software companies and the worldwide leader in multidiscipline simulation. As a trusted partner, MSC Software helps companies improve quality, save time and reduce costs associated with design and test of manufactured products. Academic institutions, researchers, and students employ MSC technology to expand individual knowledge as well as expand the horizon of simulation. MSC Software employs 1,000 professionals in 20 countries. For additional information about MSC Software's products and services, please visit www.mscsoftware.com.

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## About Dytran

*Explicit Nonlinear & Fluid Structure Interaction*

Dytran is an explicit finite element analysis (FEA) solution for analyzing complex nonlinear behavior involving permanent deformation of structures. Dytran enables you to study the structural integrity of designs to ensure that final products stand a better chance of meeting customer safety, reliability, and regulatory requirements.

With increased demand for safety and reliability of products, companies see a need for additional testing. However, destructive testing of physical prototypes is expensive and time consuming. While simulation can provide a solution, it is also important to use the right solution that is robust and accurate.

Dytran delivers a structural, material flow and coupled FSI capabilities in a single package. Dytran's explicit nonlinear solver technology is ideal for extreme, short-duration events and allows you simulate models that involve high degree of nonlinearities – material, geometric and boundary condition nonlinearities. Dytran uses a unique coupling feature that enables integrated analysis of structural components with fluids and highly deformed materials in one continuous simulation.

**Corporate**
MSC Software Corporation
2 MacArthur Place
Santa Ana, California 92707
Telephone 714.540.8900
**www.mscsoftware.com**

**Europe, Middle East, Africa**
MSC Software GmbH
Am Moosfeld 13
81829 Munich, Germany
Telephone 49.89.431.98.70

**Asia-Pacific**
MSC Software Japan LTD.
Shinjuku First West 8F
23-7 Nishi Shinjuku
1-Chome, Shinjuku-Ku
Tokyo, Japan 160-0023
Telephone 81.3.6911.1200

**Asia-Pacific**
MSC Software (S) Pte. Ltd.
100 Beach Road
#16-05 Shaw Tower
Singapore 189702
Telephone 65.6272.0082



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