Computational Modelling of Neurovascular Injuries

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Abstract

Neurovascular Injury (NVI) is a common feature of Traumatic Brain Injury (TBI). At least half TBI cases result in intracranial bleedings. [1]

- Simulation of real world accidents
  - Predict the impact of external forces on the neurovasculature
  - Understand the link between biomechanics and injury outcome
- Increase the safety of protective equipment in order to **prevent TBI**

Introduction

- TBI is the most frequent brain injury worldwide [1]
  - Long-term consequences are very likely
  - NVI immediately or as a secondary injury [2]
  - Focus on Cerebral Microbleeds (CMB), a subtype of NVI
- Relationship of force impacts and injury patterns is not well understood yet [3]
  - Computational modelling to discover the effect of external loadings on the brain that lead to fatal injuries
  - Link vascular strains to CMBs occurrence

Methodology

- Modelling of two case studies showing CMBs

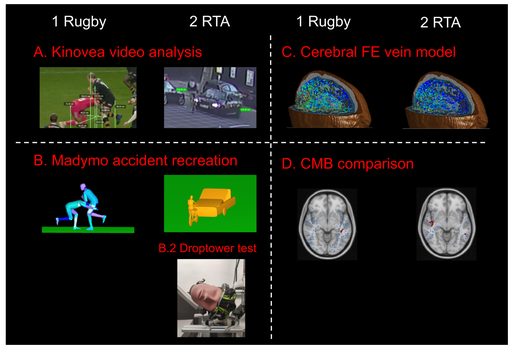


Figure 1:Research steps

Methodology

A. Kinovea Video analysis

- Get initial positions and velocities

1 Rugby

- Left player: 7 m/s, Right player: 6 m/s

2 RTA

- Bike: 3.5 - 5 m/s, Car: 12 - 14 m/s

B. Madymo accident reconstruction

- Consider contact behaviour, material properties and friction
- Choose appropriate human model and scale it accordingly

1 Rugby

- Use cervical restraints to represent neck contraction
- Head contact characteristics adapted from Yoganandan [4]
- CMBs found in the left players brain



Figure 2:Start Frame



Figure 3:End Frame

2 RTA

- Ellipsoid representations to ensure computational efficiency
- CAD models for geometry, center of gravity and inertia

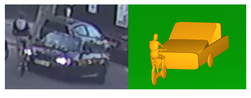


Figure 4:Start Frame

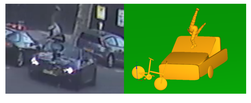


Figure 5:Middle Frame



Figure 6:End Frame

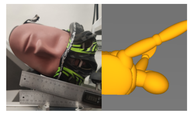


Figure 7:B.2 Droptower test

C. Cerebral FE vein model

- Segment T1 (and T2) using microimaging toolkits FSL and Freesurfer
  - Lobar and sublobar structures, csf, skull and skin
- Amalgamation of parts to create single image of head
- Process image to ensure csf surrounds brain completely, resample and smooth model
- Center of gravity in relation to Yoganandan data [5]
- Mechanical vessel properties from neurosurgical vein investigations [6]
  - Hyperelastic vein behaviour assumed

D. CMB comparison

- Visual comparison between segmented CMB areas and strains
  - Overleigh patient's neuroimage with thresholded and heatmapped strains

Results

- Crash recreations have shown high correlation with Kinovea measurements
  - Rugby case with over 90% distance correlation

1 Rugby

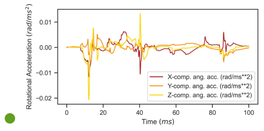


Figure 8:Rot Accelerations

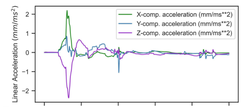


Figure 9:Lin Accelerations

2 RTA

- Madymo outputs nearly 6 m/s as z velocity
  - Droptower Test recrods 6.06 m/s ground impact velocity

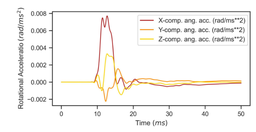


Figure 10:Rot Accelerations

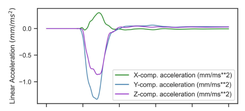


Figure 11:Lin Accelerations

1 Rugby

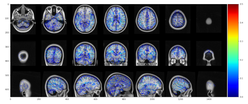


Figure 12:All strains

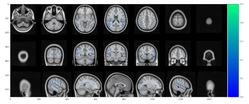


Figure 13:Strains CMB overlap

2 RTA

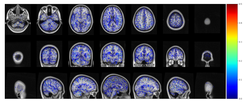


Figure 14:All Strains

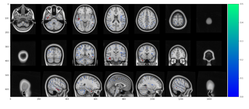


Figure 15:Strains CMB overlap

Discussion

- Full computational analysis and representation of case studies from video analysis to neuroimage comparison
- Multibody output kinematics validated by footage
- Accurate reproduction of impact conditions with Droptower test
- Cerebral Vein model: Strain output according to acceleration input

Discussion

- Encouraging results showing high strains in similar locations to pathology
- Deviations due to presumably due to use of preliminary data
- Limitations:
  - Crash recreations need assumptions and simplifications
  - Brain and blood vessel geometries and properties could differ on a case-by-case basis

Conclusion: CMB locations are predictable by independently reconstructing impact scenarios and running our brain model pipeline.

Further investigations

- Simulating ground level fall cases
- Helmet comparison of the RTA
- Scaling brain model and corresponding center of gravity
- Quantitative CMB comparison
  - Scrutinizing strain rates

References

- 1. Salehi, A., J.H. Zhang, and A. Obenaus, Response of the cerebral vasculature following traumatic brain injury. J Cereb Blood Flow Metab, 2017. 37(7): p. 2320-2339.
- 2. Kenney, K., et al., Cerebral Vascular Injury in Traumatic Brain Injury. Exp Neurol, 2016. 275 Pt 3: p. 353-366.
- 3. Yoganandan, N., et al., Biomechanics of skull fracture. J. Neurotrauma, vol. 12, no. 4, pp. 659–668, 1995.
- 4. Monson, K.L., M.I. Converse, and G.T. Manley, Cerebral blood vessel damage in traumatic brain injury. Clin Biomech (Bristol, Avon), 2019. 64: p. 98-113.
- 5. Yoganandan, N., F.A. Pintar, J. Zhang, J.L. Baisden, Physical properties of the human head: mass, center of gravity and moment of inertia. J. Biomechanics, 42 (9) (2009), pp. 1177-1192.
- 6. Monson, K. L., Mechanical and Failure Properties of Human Cerebral Blood Vessels. Dissertation, University of California, Berkeley, 2001.

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