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ON THE USE OF MECHANICAL VARIABLES FOR BRAIN INJURY PREDICTION

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Multiple mechanical variables have been used to describe the occurrence of brain injury in impact modelling of the human head [1]. The validity of these variables for this purpose is usually established through the process of matching location and extent of injury in experiments on animals with computational modelling based on specific constitutive choices for brain behaviour. In an alternative method, the ex vivo failure response of brain tissue is used as the criterion. The first method often leads to non-uniqueness because of constitutive assumptions and subjective interpretation of injury. On the other hand, the later method tends to oversimplification by correlating brain injury under complex loading to failure under idealized conditions. As a result, approximately 20 kinetic and kinematic variables are described as injury predictors in the literature.

Brain injury is classified into focal injury that occurs with immediate symptoms in a specific location and diffuse injury that occurs with delayed symptoms over a more widespread area. Both injury types can be further divided into multiple subtypes. However, mechanical variables are mostly classified by researchers to correlate with just the two major injury types with some exceptions. Three types of predictors are commonly used: point-wise (e.g. pressure, effective stress, shear stress, principal strain), volumetric and holistic. The point-wise variables are used to indicate injury at a material point, whereas volumetric and holistic measures describe injuries through critical volumes and global or integral definitions, respectively. The presence of multiple predictors for just two major injury types raises the possibility that there could be overlap, redundancy or even inaccuracy associated with them.

To investigate this possibility, a validated high-fidelity head model and the proposed mechanical variables are used to predict the time, location and extent of brain injury for comparison, under the same set of boundary and loading conditions as specified in four well-known experimental studies [2-5]. These four studies on automotive impacts have been chosen because of their predominant use in the validation of computational head models by researchers. Additionally, a pressurized-air wave (peak pressure ~450 kPa, wavelength ~1 msec) load simulating an explosive blast is also investigated for higher-rate predictions.

The results of the simulation of an impact at 45 degrees to the head (impactor mass of 5.6 kg at 9.94 m/s) [2] are provided here as an example in Figure 2. It can be seen for the focal injury that pressure is demonstrating a very different type of injury to that predicted by effective stress and principal strain. Similarly, effective stress, principal strain (31% threshold) and shear stress are predicting similar regions of diffuse injury. The obvious difference is the principal strain (5% threshold) prediction. However, one can observe that this is merely due to the calibration of the variable threshold than a fundamental difference as is seen for pressure in focal injury. One also notes that principal strain predicts both focal and diffuse injuries in the same region of the brain with different thresholds (20% and 31%). It leads to the question of how one region can have both types of injury without a physiological explanation.

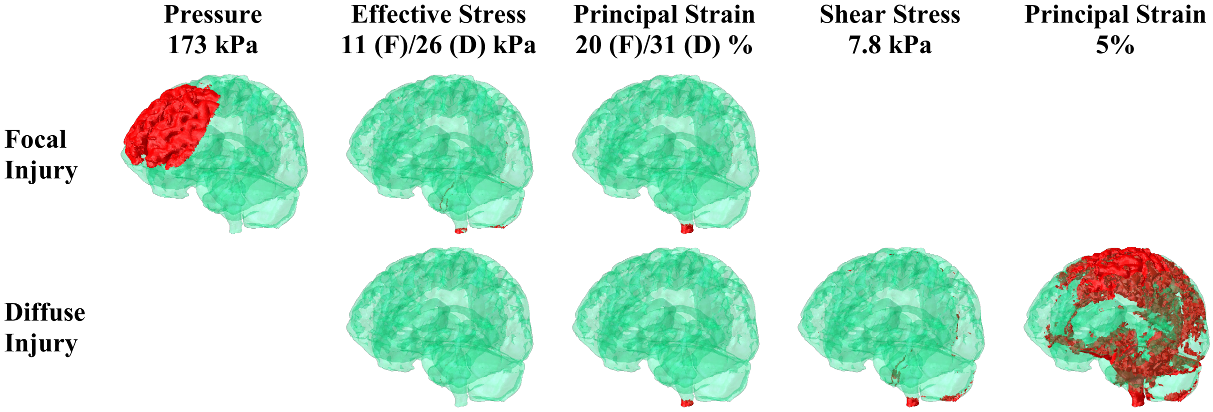

Figure 2: Spatial prediction of focal and diffuse injury accumulated over the course of the simulation based on threshold values of several mechanical variables reported in the literature.

Based on these observations and results from the other three simulations, it is concluded that the umbrella of just two injury types is very broad. It has resulted in proposals of different predictors for the same injury type or in some cases one predictor for both injury types! Effective stress, shear stress, principal strain and effective strain predictors are quite similar and thus redundant. Their differences can be resolved with rigorous thresholding based on careful experimentation. Pressure cannot define the same type of focal injury as other predictors. If focal injury (lower thresholds) occurs in a given region then diffuse injury should not be considered there or another explanation should be provided. The discrepancy between point-wise and volumetric measures can be removed, again by proper thresholding and also by similar probability calculations. Removing the influence of constitutive assumptions in determining threshold values is a paramount concern. Kinematic variables may be more suitable because they can be measured.

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