General Biomechanics of Trauma with Particular Focus on Head Trauma

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Abstract: The first part of the lecture presents general aspects of Biomechanics of Trauma including definitions and basic principles of injury causation (i.e. important physical parameters, stress/strain correlation, injury severity etc.). Common injury types and specific mechanisms are selected to demonstrate the concepts of tolerance criteria and current scientific knowledge of tolerance limits. Subject of the second part is in particular HEAD TRAUMA: Injury types and related injury causation are illustrated in view of different instances, such as traffic accidents, sports, and violence. Tolerance limits for skull fractures and brain lesions are reported as well as important injury criteria, e.g. WSTC and HIC. Examples of real cases are shown including computer simulations with human models.
Keywords: Biomechanics of trauma, general principles, head injury.

1 Introduction

Biomechanics is mechanics applied to biology. In particular, biomechanics of trauma to the human body includes the following mechanical problems: a) Stress and strain distribution in materials (bones, soft tissue, fluids); b) Constitutive equations which describe mechanical properties of materials; c) Strength of materials, yielding creep, crack propagation, fracture, fatigue failure etc.[1]. The objective of this lecture is to demonstrate basic principles of injury causation (i.e. important physical parameters, stress/strain correlation, injury severity etc.). Common injury types and specific mechanisms are selected to explain the concepts of tolerance criteria and current scientific knowledge of tolerance limits. Particularly focussed are head injuries, e.g. Diffuse Axonal Injury (DAI), discussing injury types, tolerance limits and criteria and computer simulations with human models.

2 Injury Mechanisms and Tolerance

Mechanical loading affecting the human body (impact, acceleration) has the potential to cause trauma, which is mechanical or physiological damage and/or dysfunction of body parts (bones, organs, tissue). Specific injury mechanisms can be classified qualitatively (direct, indirect, blunt, sharp) and quantitatively. Dependent on injury type the physical parameters suitable to describe biomechanical loading are the following: Force (contact or internal), acceleration (linear and rotational), moment (bending, torsion), energy, pressure, deflection. Identification and understanding of injury mechanisms is one of the main objectives of research in the field of trauma biomechanics. As an example, Figure 1 illustrates the loading situation of a long bone bending fracture (e.g. tibia): Computer simulation (model) and experimental data (Kallieris 1,2,3.[2]) are compared to show the typical force-displacement history and failure (fracture) at approx. 9 mm displacement and 2.9 kN bending force Closely linked with quantitative description of injury types is the determination of associated tolerance limits. They indicate, mostly in terms of force or g-level, two different thresholds: The Lower tolerance limit as the highest value for which an injury was never observed in the whole population, and the Upper Tolerance limit as the lowest value for which an injury is observed in the whole population.

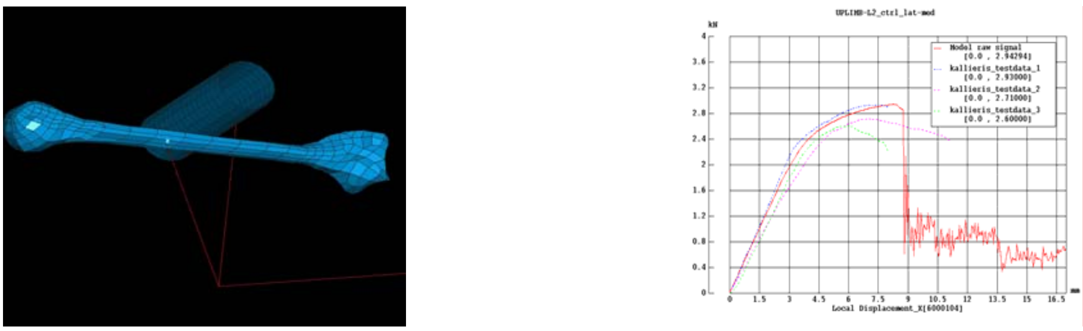

Figure 1: Bending of a long bone – tolerance for fracture

Examples of lower tolerance limits for some body parts are listed below:

Whole Body:	40-45 g (160-220 ms), 10 g (1–2 s),
Thorax	Frontal 60 g (3 ms); 58 mm deflection,
Abdomen:	Lateral 2500 N, Frontal 1500 N,
Tibia:	Frontal Force 2.5-5 kN,
Femur:	Axial Force 8-10 kN.

<u>Injury Criteria</u> are established to estimate the probability of a specific injury and loading situation. HIC is best known injury criterion applicable in frontal head impact situations. Other injury criteria are for instance: NIC (Neck Injury Criterion), TTI (Thorax Trauma Index) and v*c (Viscous Criterion) [3].

2.1 Head Injury

Head injury can occur from direct head impact (contact force) or inertial loading (linear and/or rotational acceleration). Direct impacts can cause local lesions in form of linear skull fractures, epidural hematoma and brain contusions. Possible remote lesions are base fractures and intra cerebral hematoma. Inertial head loading resulting from acceleration (linear & rotational) can cause Subdural

Hematoma (bridging vein rupture) and Diffuse Axonal Injury (DAI).

Some values of tolerance limits are:

Cranium (fracture):

Forehead	Fx	4300 N,
Temple	Fy	2500 N,

Brain:

Concussion	80 g (10ms).

2.1.1 Diffuse Brain Injury (DAI)

Diffuse Axonal Injury (DAI) is a common brain lesion in all kinds of fatal traffic accidents, such as car occupants, pedestrians, motorcycle and bicycle riders. From an own real accident study completed at LMU in 2002[4] significant injury mechanisms causing DAI were identified. Detailed investigation of injury patterns indicate that DAI in brain stem and medulla oblongata occurs in cases exposed to axial linear acceleration of the head ($\pm g_z$). DAI in the corpus callosum region is caused when rotational head acceleration around vertical z-axis is predominant. Shear forces due to extensive skull deformation and tensile forces, in particular parietal, are causing DAI in the hemispheres. DAI tolerance limits are identified as follows (c.f. Fig. 2 – 4): (a) Mean linear acceleration 130 g for short duration (10 ms) and 110 g for longer duration (20 ms); (b) Rotational velocity 38 rad/s at 7.500 rad/s², and (c) Rotational acceleration 5,500 rad/s² for short duration (10 ms) and 3,500 rad/s² for longer duration (20 ms).

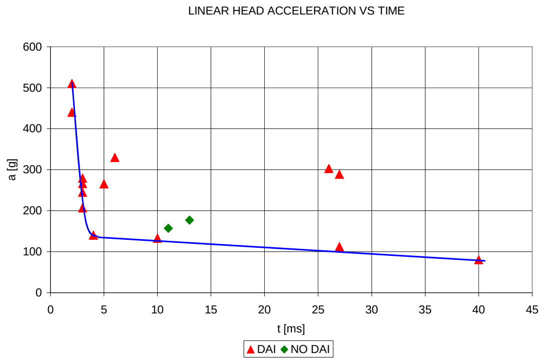

Figure 2

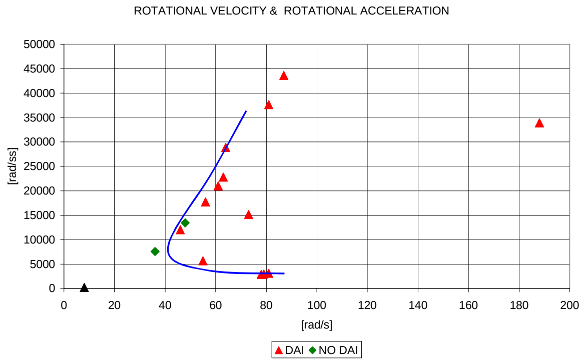

Figure 3

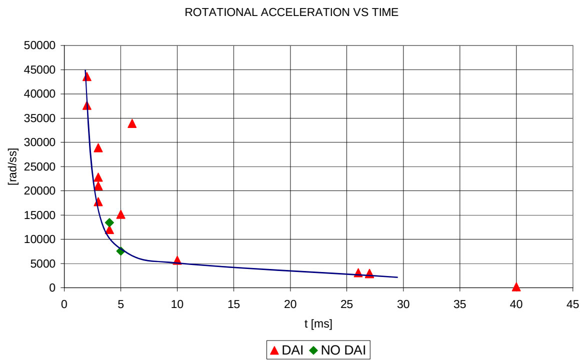

Figure 4

3 Conclusion

A brief overview of trauma biomechanics is presented examining basic principles of injury causation, injury mechanisms, injury tolerance and injury criteria. Tolerance limits of specific lesions in various body regions (thorax, abdomen, tibia etc.) are reported. Head injury is emphasized demonstrating injury types and their tolerance limits. Detailed values derived from an own accident study on are given for Diffuse Axonal Injury (DAI).

Reference

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