H8 Modeling of Inflicted Head Injury by Shaking in Children—What Can We Learn? Part 2: Mathematical and Physical Models

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Learning Overview: After attending this presentation, attendees will: (1) be familiar with the different types of mathematical and physical models that have been used to investigate inflicted head injury by shaking in children, (2) learn about the strengths and limitations of these models and their underlying injury thresholds, and (3) learn how to put into perspective the various claims in the field about inflicted head injury by shaking in children.

Impact on the Forensic Science Community: This presentation will impact the forensic science community by showing medical and legal practitioners who are not biomechanically trained to better put the claims made in the literature into perspective. This is crucial for proper interpretation of injuries in alleged abusive head trauma cases.

Various types of complex biomechanical models have been published in the literature to better understand processes related to Inflicted Head Injury by Shaking in Children (IHI-CS). The wide variety of model types and modelling approaches makes it hard to compare these models to each other and value their—sometimes contradictory—conclusions with respect to the likelihood of pediatric head injury occurring due to shaking. A systematic review was conducted to categorize the available modelling studies and to enable better comparison of these studies.

MEDLINE® and Scopus® were used to find studies applying physical (such as dolls) and mathematical (computer simulation) biomechanical models for shaken induced head injury in children up to January 1, 2017. After de-duplication, the found articles were independently screened by two researchers using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. Data extracted from the papers is represented in a "7-Steps Description" of IHI-CS, addressing the sequence of mechanical events that take place in a child subjected to shaking.

The initial database search yielded 1,977 papers, of which 11 papers on physical models and 23 papers on mathematical models were included after the selection process. In both categories, some models focus on describing gross head kinematics during shaking events, while others address the behavior of internal head and eye structures in various levels of detail.

In the 7-Steps Description, an IHI event is initiated with a shaking motion exerted onto the infant's torso: the "torso dynamics," which is the input at Step 1. That motion is transferred by the neck to the head in Step 2 "torso-skull transfer," which results in the "skull dynamics" at Step 3. In turn, these skull dynamics determine in Step 4 "skull-internal transfer," how everything inside the skull moves and deforms, resulting in the "internal dynamics" at Step 5. Internal dynamics include loading and deformation of the anatomical elements inside the skull, such as pressure acting on the eyes or strains acting on the bridging veins. The dynamics of internal anatomical elements may lead to damage of these elements if their threshold for material damage is exceeded in Step 6 "injury thresholds," which then gives rise to "injury" in Step 7.

In virtually all mechanical and mathematical models analyzed, injury thresholds were derived from scaled non-infant data. Studies focusing on head kinematics often used injury thresholds derived from impact studies. Physical modelling studies as well as some mathematical models focusing on head kinematics often conclude that shaking alone cannot produce injury. However, mechanical models containing detailed head anatomy, as well as mathematical models containing a detailed description of structures inside the infant head and eye suggest that shaking events can indeed produce injuries, such as bridging vein rupture and retinal hemorrhaging. Besides this, several of the studies analyzed hinted at the possibility that the injury mechanism during shaking is fundamentally different from that during impact. Mechanical effects in which shaking likely differs from impact include build-up of pressure within the head over multiple shaking cycles, resonance effects, and a slower, but potentially higher, transfer of deformation energy.

Future research focusing on determining injury thresholds for infant biological material is urgently called for. This holds both for macroscopic anatomical data, such as stiffness of the infant neck, as well as for microscopic data, such as the failure stretches of infant bridging veins. Also, possible other injury mechanisms during shaking should be further investigated, because there seem to be clear indications that the currently often-made comparisons of shaking events with impact injury thresholds may not be valid.

Closed Head Injuries, Child Abuse, Rigid Body and Finite Element Model