the test conditions used to arrive at thresholds (eg, impact, indirect loading), and the injury type (eg, subdural hemorrhage, cerebral concussion).[257] Scaling from adult injury models may fail to capture anatomical differences of the immature skull (eg, open fontanelle) and brain (eg, composition, extent of myelination).[258,259] Additionally, the physiological response of an immature brain to dynamic loading has also been shown to differ from that of an adult brain, further undermining injury predictions based on scaled adult thresholds.[260]

Computational Models and Simulations

Computer models incorporating 3-dimensional (3D) digital humans or body segments (eg, head) in a virtual environment (eg, fall environment, motor vehicle crash) can be used to simulate potentially injurious events such as falls.[261–264] Anatomic accuracy and biofidelic response are key in the development of 3D digital human models. Similar to surrogates, 3D human models may be equipped with virtual sensors to predict biomechanical measures. The motion and response of human models are governed by user-defined body characteristics and the laws of physics; they are not animations.

Animal Injury Models

Animal models have been used to gain further understanding of injury mechanisms and injury thresholds since this information is otherwise not attainable using human subjects. Ensuring translatable outcomes to humans and animal welfare are key to animal injury models. The animal or animal specimen must represent the equivalent human structure and function with appropriate scaling for differences in mass, maturation, or material properties, and the animal's biologic response should parallel that of the human population as much as possible.

Animal models of inflicted injury have been used in a number of contexts, with most studies focusing on 2 main research areas. The first category employs animal models to gain insights into possible mechanisms of injury. Such studies reflect the premise that by subjecting an animal to similar mechanical phenomena (eg, forces, accelerations) that an infant or child might experience during an abusive event, the resultant injuries potentially reflect injuries that may happen in humans and, thus, enable investigators to better understand injury mechanisms. Such models might also advance our understanding of predictors of outcome or response to interventions.

The second main use of animal models is to facilitate the study of factors influencing pathophysiology and evolution of injury. Such factors might include maturational stage, specific types of insults, or stressors that might exacerbate damage. This approach applies a specific insult or combination of insults thought to be part of abusive head trauma and evaluates the effects of relevant controlled variables to assess the comparative evolution of injury and, in some instances, to investigate prognostic variables or response to treatment. Specific models are described in more detail below.

Postmortem Human Subject Experiments

PMHS experiments simulating potentially injurious events can provide insight into injury mechanisms, injury types resulting from exposure to mechanical phenomena such as acceleration or force, and injury thresholds. PMHS studies have the advantage of accurate anatomic representation and biomechanical response of the targeted human population. However, the lack of PMHS vascular perfusion and respiratory inflation, the presence of rigor mortis, and the use of preservation techniques could alter biomechanical response compared with living humans.

What Can We Learn From Biomechanical Studies Focused on AHT?

As discussed earlier, different types of biomechanical studies have been used to address questions related to pediatric head injury. These studies have investigated pediatric head injury risk related to forceful impact and shaking mechanisms.[250,251] It is important to note that this is not an exhaustive review of the biomechanics scientific literature related to pediatric head trauma.

Diffuse brain injuries and/or focal brain injuries can occur in AHT. These distinct types of injuries are caused by exposure to different physical phenomena. When a child is subjected to violence, the forces and accelerations they are exposed to are likely complex in nature and may include a combination of direct and indirect forces, along with angular and linear accelerations.

Biomechanical studies have demonstrated that direct or indirect forces applied to the body leading to rotation of the head and angular head acceleration can cause diffuse brain injuries, such as diffuse axonal injury, concussion, or a subdural/subarachnoid hemorrhage that often is in a more widespread distribution rather than being very focal.[265–268] Conversely, forces applied to the body that generate linear motion of the head and translational head acceleration can cause focal brain injuries, such as brain contusions or focal subdural hemorrhage. Impact forces applied directly to the head can also lead scalp contusions, subgaleal hemorrhage, and/or skull fractures as well as intracranial contusions and focal intracranial hemorrhages.

Forceful impacts onto hard surfaces are likely to cause skull fractures and focal brain injuries (eg, brain contusion, epidural hemorrhages, focal subarachnoid or subdural hemorrhage), but sudden deceleration against even a softer surface may also generate rotational accelerations at levels capable of producing diffuse brain injuries (eg, concussion, subdural hemorrhage, diffuse axonal injury).[269,270]