C36 Catastrophic Neck Injuries Can Result From Low Height Trampoline Jumps

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The goal of this presentation is to demonstrate that simple articulated rigid body models can be used to predict catastrophic neck injuries from simple backward falls while jumping gently on a trampoline.

Trampoline injuries account for about 100,000 hospital emergency department visits per year. While catastrophic cervical spine injuries are rare, head and neck injuries constitute a notable number of the more serious trampoline injuries requiring hospitalization. The prevailing view is that cervical spine injuries associated with trampoline use are the consequence of failed attempts at aerial maneuvers such as back flips and summersaults. However, in one instance of cervical spinal cord injury, it was alleged that a male subject was simply jumping vertically and stiff-legged a few inches off a trampoline mat, when his feet slipped rapidly out from under him, causing him to rotate backwards, and strike the back of his head on the mat. He sustained a C4/5 fracture subluxation accompanied by a spinal cord injury that resulted in quadriplegia and permanent neurological deficit. The main objective of the authors was to determine if a slip and backward fall, even while jumping gently on a trampoline, was a plausible mechanism for this injury. A secondary goal was to develop a general model for predicting injury risk associated with backward falls on trampolines for subjects of various heights and weights, including women and children.

Methods. The subject was modeled as two rigid bodies connected with a planar pin joint at the neck. The neck joint was modeled using a torsional spring and damper with the torsional spring assumed active only outside a dead band. The damper was assumed to have constant properties throughout the range of motion. Using appropriate initial conditions, the equations of motion were numerically integrated forward in time, using a 4th order Runge-Kutta algorithm. The Abbreviated Injury Scale (AIS) was used to describe the severity of neck injury. The predicted neck forces were compared against the tolerance limits for the human cervical spine (FMVSS 208) The criteria are referred to as N_{ij}, where the “ij” represent indices for injury in compression, tension, flexion and extension. Validation experiments were conducted using a Hybrid III crash dummy, representing a 5th percentile female. Dummy kinematics from drop experiments onto an exemplar trampoline were digitized from high-speed video. Trampoline stiffness and damping were determined by dropping a bowling ball from various heights. Friction properties between sock and mat were determined with a pull meter.

Results. There was excellent agreement (within a few percent) between angular orientation measured during experiments with the Hybrid III dummy and the angular orientation predicted by the simulation. The dummy was nearly vertical initially and then rapidly rotated backward after initial impact of the feet with the trampoline mat, resulting in impact on the back of the head as the dummy rotated past the horizontal. For the 95th percentile male involved in the incident under litigation, the kinematics were similar, with a large rapid rotation predicted as the slipping feet are accelerated vertically by the rebounding mat. As the back of the head then contacts the mat, vertical forces result in flexion moments on the cervical spine sufficient to exceed neck injury criteria.

Discussion. There is a large literature on the biodynamics of gymnastics, diving and other sport and space flight related activities that require self-rotations while in flight. There is also a rapidly growing literature on the biodynamics of falls and their relationship to injuries of the hip and spine. Finally, because of the public health importance and fiscal impact of catastrophic injuries to the neck, the last three decades have seen important advances in our understanding of the injury thresholds and tolerance limits of the human cervical spine. Unfortunately, these approaches have seldom been applied to the use of trampolines. The fundamental issue sought to address was whether or not a slip and backward fall on a trampoline could cause serious injury. The results demonstrate a serious injury mechanism peculiar to trampolines. When slipping and falling backward while jumping even gently on a trampoline, the subject can be “whipped” backwards by a strong upward force exerted by the trampoline mat on the slipping feet. This causes the body to rotate through a large angle so that the head directly impacts the trampoline surface, producing loads on the head sufficient to result in catastrophic injury to the cervical spine for subjects ranging from a 5th percentile female to a 95th percentile male. This, to the author’s knowledge, is the first analytic model for injury prediction from jumping on a trampoline. While simple, the model incorporates the major features of the trampoline response, the biodynamics of the jumper’s motion, and the interaction between the jumper’s feet and the mat. The model was validated using a modern Hybrid III crash dummy and a full-scale exemplar trampoline. The model did not reflect the distribution of mass and mass moments of inertia that might be possible through use of a multi-segment articulated total body model. However, the two-link model achieved excellent agreement between analytic predictions and direct experimental measurements, a finding that lends additional credence to the modeling approach. Ongoing work is extending these approaches to a consideration of comparable neck injuries in children, a consideration of multi-link articulated body models, and more complex representations of trampoline properties.

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