Significant Spinal Injury Resulting From Low-Level Accelerations: A Case Series of Roller Coaster Injuries

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FROM ABSTRACT:

Objectives
To describe a cohort of significantly injured roller coaster riders and the likely levels of acceleration at which the injuries occurred, and to compare these data with contemporary efforts to define a lower limit of acceleration below which no significant spinal injury is likely to occur.

Design
A retrospective case series of roller coaster ride–induced significant spinal injuries.

Setting
Injury incident records and emergency medical service records for the Rattler roller coaster in San Antonio, TX, were evaluated for a 19-month period in 1992 and 1993. Medical records for the more significant injuries were also reviewed and the specific injuries were tabulated, along with the demographics of the cohort.

Participants
There were 932,000 riders of the Rattler roller coaster, estimated to represent between 300,000 and 600,000 individual riders.

Main Outcome Measures
Injury incident reports and medical record review.

Results
It is estimated that there were a total of 656 neck and back injuries during the study period, and 39 were considered significant by the study inclusion criteria.

Seventy-two percent (28/39) of the injured subjects sustained a cervical disk injury; 71% of these injuries were at C5-6 (15 disk herniations, 5 symptomatic disk bulges) and 54% were at C6-7 (11 disk herniations, 4 symptomatic disk bulges).

In the lumbar spine, the most frequent injury was a symptomatic disk bulge (20% of the cohort), followed by vertebral body compression fracture (18%), and L4-5 or L5-S1 disk herniation (13%).
Accelerometry testing of passengers and train cars indicated a peak of 4.5 to 5g of vertical or axial acceleration and 1.5g of lateral acceleration over approximately 100ms (0.1s) on both.

Conclusions
The results of this study suggest that there is no established minimum threshold of significant spine injury.

The greatest explanation for injury from traumatic loading of the spine is individual susceptibility to injury, an unpredictable variable.

THESE AUTHORS ALSO NOTE:

The results of experimental studies to gauge risk of injury to traumatically induced spine loads cannot be extrapolated to an injury threshold for real-world crashes, because such crashes do not involve cadavers or human volunteers resisting a static load.

Peak head acceleration is not a valid construct for the injuriousness of an event because it has been shown that some people will sustain neck injury at lower levels of peak head acceleration than others.

In real-world vehicle crashes, there is a wide variability of crash conditions and factors relating to occupant injury susceptibility, which are not factored in experimental studies.

Experimental studies “cannot be used to establish a minimum injury threshold for real-world crashes.”

A problem associated with the collection of information from volunteer crash testing is that they use healthy and informed subjects, and subject them to an event that is least likely to result in injury. [Very Important]

“Real-world crash victims are not necessarily healthy, never informed, and the crashes occur in a random fashion.” [Very Important]

“A human volunteer crash test from which no injury results provides evidence that it is possible to undergo such testing without sustaining injury,” but gives no indication as to whether injury can occur in real-world crashes at similar force levels.

Significant spine injuries like disk herniation are a relatively rare occurrence with minimal-damage crashes, and [therefore can never be assessed in experimental studies that involve only a few healthy, warned, anticipating volunteers].
The change in vehicle velocity is often used by accident reconstructions to estimate the head acceleration (g force) experienced by the occupant. Yet, studies show that a 5-mph change in velocity can generate head peak acceleration ranging from 6.7 to 12g among individuals who were all seated in the same vehicle in near identical position. [Important]

“There is significant inherent error in attempting to predict peak head acceleration by relying solely on vehicle velocity change.”

Typical roller coaster ride peak car accelerations are 2 to 3g.

Injuries do occur on roller coasters. There were 10,700 emergency department visits in 2000 resulting from amusement park ride injuries, many from roller coasters.

Documented roller coaster ride injuries to the brain include subdural hematoma, vertebrobasilar artery dissection, carotid artery occlusion, and subarachnoid hemorrhage.

The patients in this study had significant spinal injury that had an incident report and/or emergency medical response report reflecting immediate onset of symptoms following the roller coaster ride; medical records described a diagnostic severity level more serious than sprain or strain (eg, disk or bony injury); and diagnostic imaging that validated the diagnosis (ie, magnetic resonance imaging, computed tomography, plain radiography).

In a 4-month period of time from one location, there were 138 spinal injuries reported and an estimated 600 to 700 neck and back injuries total. 39 of the injuries were significant: 23% were male and 77% were female, with a mean age of 37.4 years.

72% (28/39) sustained a cervical disk injury
2% (1 case) sustained cervical vertebral body compression fracture (C5)
2% (1 case) sustained a spinal cord contusion secondary to a displaced os odontoideum in a 12-year-old girl

20% had a lumbar spine disk bulge
18% had a lumbar spine vertebral body compression fracture
13% had a lumbar spine herniated nucleus pulposus

Treatment for the injuries was surgery in 56% (22/39) of cases.

Most of the injuries occurred during the first drop of the roller coaster. Accelerometry testing of passengers passing through the first drop produced 4.5 to 5.0g of vertical or axial acceleration and 1.5g of lateral acceleration over approximately 100ms on the occupants.
DISCUSSION

In this analysis, females comprised of 77% of the injured subjects, a finding that is in agreement with other authors who have reported increased female injury in real-world crashes.

Biomechanically derived injury threshold of peak head acceleration are based on averages derived from experimental studies of prepared and healthy volunteers and cadavers, which are “populations that cannot serve as valid surrogates for the general population.”

There is no credible evidence at the present time that an experimentally derived threshold exists for cervical spine injuries, and if it did, “it would be unlikely to include the minority of the population that is at risk of significant spine injury in low-level accelerations.”

Other studies have proven that peak head accelerations are a poor indicator for the injury. Peak head acceleration does not reflect the level of force transmitted to the spine, and therefore does not correlate with spinal injury. Peak head acceleration is not directly correlated to the “injuriousness of rear-impact acceleration.”

Studies now document that during rear-impact collisions, “injurious aberrant intersegmental motion in the cervical spine occurs before rearward rotation and peak acceleration of the head.”

The variables most likely to be related to injury are “physical condition, individual head-neck-torso geometry, and degree of preparatory muscular bracing of the individual subjects at the time of the exposure to the peak accelerations.”

Therefore, in real-world rear-impact collisions, the range from no injury, to mild injury, to significant injury and disability can occur.

CONCLUSIONS

One cannot use “peak head acceleration levels as a means of determining the probability of significant spine injury following low-level accelerations.”

The injury rate for real-world motor vehicle crashes is likely to be significantly higher than those from roller coasters because roller coaster riders are warned and aware of the impending accelerations. None of the riders were likely to have been exposed to more than 5 or 6g of peak head acceleration. “In contrast, occupants exposed to real-world rear-impact collisions are typically not prepared for the acceleration, and do not have the opportunity to elect out of the sudden acceleration.”
In addition, “Real-world crash victims represent a random sampling of the population; roller coaster riders are more likely to be healthy and young risk takers.”

Also, “Experimental rear-impact no-damage collisions have been shown to produce more than 15g peak head acceleration, more than 3 times the amount of peak head acceleration measured on the roller coaster.”

“Based on the results of this study, it is apparent that in a susceptible subset of the relatively healthy general population, significant spinal injury can result from low-level accelerations.” [Key Point]

KEY POINTS FROM DAN MURPHY:

1) Roller coaster accelerations can cause serious injuries, including cervical disk injuries (including disk herniations and bulges), and 54% were at C6-7 (11 disk herniations, 4 symptomatic disk bulges), and vertebral body compression fractures, both of the cervical and lumbar spines.

2) Roller coaster accelerations can injure the brain including subdural hematoma, vertebrobasilar artery dissection, carotid artery occlusion, and subarachnoid hemorrhage.

3) There is no established minimum threshold of significant spine injury.

4) The best explanation for injury from traumatic loading of the spine is individual susceptibility to injury, which is an unpredictable variable.

5) Experimental trauma to the spine cannot be extrapolated to an injury threshold for real-world crashes, because such crashes do not involve cadavers or human volunteers resisting a static load.

6) Peak head acceleration is not valid in assessing the injuriousness of an event because some people will sustain neck injury at lower levels of peak head acceleration than others.

7) Experimental studies “cannot be used to establish a minimum injury threshold for real-world crashes.”

8) Information from volunteer crash testing is flawed because they use healthy and informed subjects, and subject them to an event that is least likely to result in injury. [Very Important]

9) “Real-world crash victims are not necessarily healthy, never informed, and the crashes occur in a random fashion.” [Very Important]
10) A 5-mph change in velocity can generate peak head accelerations ranging from 6.7 to 12g among individuals who were all seated in the same vehicle in near identical position. [Important]

11) “There is significant inherent error in attempting to predict peak head acceleration by relying solely on vehicle velocity change.”

12) This study indicates that females are injured four times more than men in the same acceleration exposure.

13) The variables most likely to be related to injury are “physical condition, individual head-neck-torso geometry, and degree of preparatory muscular bracing of the individual subjects at the time of the exposure to the peak accelerations.”

14) One cannot use “peak head acceleration levels as a means of determining the probability of significant spine injury following low-level accelerations.”

15) Experimental rear-impact no-damage collisions have been shown to produce more than 15g peak head acceleration, more than 3 times the amount of peak head acceleration measured on the roller coaster.

16) In a susceptible subset of the relatively healthy general population, significant spinal injury can result from low-level accelerations. [Key Point]