INTRODUCTION: The level of force at which significant spinal injury can occur is a topic that has generated much discussion in the literature over the past 30 years. Various authors have attempted to experimentally quantify a minimum threshold for spinal injury in motor vehicle crashes (MVC) by examining the human response to low speed crash testing using both live volunteers, cadavers, and anthropomorphic dummies. Due to wide variability in vehicles, crash conditions, and factors relating to occupant injury susceptibility, the results of such studies are typically not generalizable to the at-risk population, and while they may give a crude estimate of average injury thresholds, they cannot establish a minimum injury threshold. Ethical constraints dictate that crash testing be accomplished with healthy and informed subjects, and neither condition is necessarily present in actual crashes. For this reason, research pertaining to human injury thresholds is best accomplished with observational study; that is, analysis of real world events. Such study is difficult with MVC-induced injury patterns, as it is not always feasible to accurately determine the amount of force that occurred in a crash after the fact, something that is essential if an injury threshold is to be derived. An ideal opportunity for study is presented with amusement park rides; roller coasters in particular. Roller coasters deliver a near identical level of acceleration to hundreds of thousands of subjects over a period of years, making them a naturally occurring laboratory of human response to relatively low level accelerations. Typically, the rides deliver peak occupant force of several \( \text{g} \), but in attempting to make the rides more exciting, some roller coaster manufacturers have increased the level of rider acceleration to the point that injury can occur. While roller coaster injuries to the brain have been documented, a comprehensive literature review revealed no documented injuries of the spine, in spite of the fact that many rides have visibly posted signs cautioning prospective riders with neck or back problems to beware. One such ride was the Rattler Roller Coaster, in San Antonio, Texas, which operated from 1992-1997. One particular corner was found to generate \( 6 \text{g} \) of peak head acceleration into lateral flexion and axial loading over approximately 100 msecs, an acceleration level and duration that is similar to that generated by a 3-4 mph rear-impact collision, and one that produced numerous claims of injury during the period of time that the Rattler was in operation. This “naturally occurring” consistent level of acceleration presented an ideal venue for study of the effect of low levels of acceleration on large populations.

METHODS: Injury incident records kept by the operators of the Rattler Roller coaster for the period 3-28-92 through 10-22-93 (approximately 19 months) were examined for significant (more serious than a sprain or strain) spinal injuries that occurred on the ride, most of which were identified as taking place at a particular turn (turn eight) on the ride. Additionally, emergency medical response and medical records that pertained to the incident records were identified and reviewed. The date of injury, age, gender, and height and weight of the injured subjects were tabulated, along with the type of injury and subsequent treatment.

RESULTS: A total of 39 subjects (out of an estimated 300,000 riders) with significant spinal injuries were found, yielding an injury rate of 13/100,000 exposures. The injuries were as follows; 72% (28 of 39) were single or multilevel cervical disc herniations (61% at C5-6 [17 of 28], 50% at C6-7 [14 of 28]), 23% were lumbar or thoracolumbar disc herniations (9 of 39), and 18% were spinal fractures (seven cases, one cervical and six lumbar). There were two cases of tetraplegia; one temporary case in a 12 yo female with a contused cord associated with an os odontoideum, and the other a permanent partial condition resulting from a central stenosis following a C5-6 and 6-7 central disc herniation and subsequent surgical decompression. Treatment for the injuries was surgery in 56% (22 of 39) cases, with the majority (77%) requiring anterior cervical discectomy and fusion. The subjects were 77% female and 23% male, and the average age was 37.4 (SD=9.1). The average Body Mass Index (BMI) was 23.1 (SD=4.4) for the females and 22.6 (SD=3.7) for the males, indicating average height and weight of the subjects.

DISCUSSION/CONCLUSION: The primary risk factors for significant spinal injury following exposure to the low level accelerations in the present study are female gender and age ranging from late 20's to mid 40's, presumably older than the average uninjured roller coaster rider. This finding concurs with recent publications demonstrating that females sustain higher levels of peak head acceleration than males in volunteer crash testing (presumably due to the greater head-neck ratio), and that disc degenerative changes begin at the end of the third decade. While the injury rate was quite low (one in 7700 riders), the results of this study illustrate the fact that it is very difficult to rule out the possibility of significant spine injury in low level accelerations. Given the fact that no-damage MVCs can...
produce more than 15g peak head acceleration, it is not surprising that many spine surgeons find a significant minority of their patients presenting with a history of injury following a low speed crash.