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Forensic BIO-Engineering Analysis to the Head from a Falling Picture Frame

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Abstract

This paper concerns the biomechanical evaluation of the injuries arising from an injury-causing accident. The presentation will involve the assessment of how the events related to and the likelihood the impact caused the injuries and/or the symptoms that were claimed in the legal proceedings. The likelihood that the injury has occurred from this, relates to both the duration of the symptoms and the recovery as well as the appropriateness of the treatment that was received. This analysis was conducted in opposition to that produced by the plaintiff's forensic expert including his evaluation of the threshold levels that were reached or exceeded. The question should be: Should the event be judged as a likely source to have caused the symptoms that were reported or claimed, and did the recovery match the medical intervention and meet the expected guidelines for this array of symptoms.

Keywords

Head, Neck, Head Impact, Concussion, Vertebrae, Teeth, Recovery.

This accident occurred when a family was having a Christmas celebration in a hotel in New York City. On the wall above the fireplace was a flat-screen television with a surrounding picture frame as part of the decoration. This picture frame was initially mounted to the wall, and as mounted, did not make contact with the television. Apparently, at some time prior to the accident, the picture frame was removed from the wall by disengaging the wall mounts on the back of the picture frame. Upon reinstallation, the picture was not reinstalled using the mounting hardware to engage the screw fasteners in the wall, but rather just hung on the top of the television. From a photograph of the arrangement on the evening of the event,

Photo 1
Prior to accident

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the plaintiff can be seen seated on an ottoman in front of the fireplace and the picture frame surrounds the television. It can be seen that the spacing between the television and the picture frame is not uniform. There is no gap between the top of the television and the picture frame. There is a noticeable gap at the bottom and there are larger gaps at the sides.

Hence, the holding force keeping the picture frame in place appeared to be only the weight of the picture frame producing a friction force against the top of the television. Photo 2 shows the picture frame with surrounding scales. Its weight was slightly more than 20 pounds.

Photo 2
Picture Frame with scales

The accident occurred when one of the attendees to the party was moving something on the mantle above the fireplace and dislodged the picture frame from its resting place on top of the television. The picture frame then fell vertically down fell down to impact the mantle surface and then rotated away from the wall. When the top of the frame had rotated about 90 degrees and was level with the mantle surface, it hit the crown of the head of the plaintiff. Initially, the plaintiff appeared to suffer no immediate trauma except for a 0.3 millimeter (.012 inch) laceration in her scalp, as noted in the emergency room records. Photo 3 shows the location and extent of the laceration.

No appreciable bleeding was noted nor was there any surgical dressing applied to the laceration when the plaintiff went to the Emergency Room of a local hospital several hours after the event. From an outside observer's standpoint, the injury did not seem to be serious because the Plaintiff had remained in the hotel room for a few hours, after which time it was decided to go to the Emergency Room for diagnosis and treatment. She was evaluated at the hospital, given the diagnosis of having a Closed Head Injury and Scalp abrasion. She was sent home with some analgesics (pain medication) and told to obtain follow-up treatment with her private physician once she returned to her home.

Photo 3
Location of Scalp Laceration

After arriving at her home in another city, she proceeded to seek further medical care. She also obtained representation by an attorney. Subsequent to this, she claimed to have developed symptoms from this impact to her head that could be summarized as:

1. Scalp Laceration
2. Closed Head Injury (concussion)
3. Cervical Neck Injury, and
4. Dental Fractures

Assessment of these claimed injuries/symptoms will be taken in the order listed above.

The force on the crown of her head was interpreted as having a load path that transmitted through her structural anatomy. From the force that caused the scalp laceration, she sustained a concussion from the impact to the crown of her skull, and as a consequence of having the spinal column support the skull, a compressive injury to her cervical vertebrae which resulted in medical procedures to replace of two cervical disks and a fusing of a third. And finally, a number of teeth were damaged as a consequence of the motion of the skull from the impact where the mandibular jaw motion caused the teeth to come together at high velocity fracturing several teeth. A brief mention of Temporomandibular Joint injury was made but not claimed in the light of the more serious cervical neck injuring claim and subsequent surgical intervention.

1. Scalp Laceration

No treatment was proscribed at the time of presentation at the Emergency Room of the hospital. No stiches were used to close the wound nor was there any surgical dressing applied. No further mention of this injury was mention in the proceedings. This seems to the outside observer the most obvious injury sustained from the accident. It was not disputed that she suffered a scalp laceration.

2. Closed Head Injury

The claim of a closed head injury, or commonly known of as a concussion, is often claimed from collision-related accidents. Often the symptoms are self-diagnosed and reported as subjective in nature, not having an objective measure for assessment. It is difficult to assess the reality of claimed subjective symptoms such as headaches, memory loss, cognitive defects and dizziness. However, the requirement to understand the design of personal protective measures in automotive design and sports equipment has resulted in a quantitative evaluation of head impact that can be related to the likelihood of injury. The ability to design vehicles and products that can be evaluated as providing a measurable level of safety has been the task of engineers. The historical assessment of quantitatively measuring the risk of head injury was initially based upon the work of Gadd (1961) with the Gadd Severity Index, GSI (1966), and later the Wayne State Tolerance Curve. The current version of the evaluation is known as the Head Injury Criterion, HIC, and was adopted by the National Highway Traffic Safety Administration in the Federal Motor Vehicle Safety Standard, FMVSS 208. With this as a background for the evaluation of an acceleration pulse to the head, the progressive level of safety in the design of vehicles and personal protective equipment has been possible for engineers. The companion to the HIC calculation was the development of risk assessments for varying values of HIC values, and the development of threshold values and evaluation of the effects of additional factors such as age, gender and body size.

The assessment of a potential concussion-causing event has been treated from an injury biomechanics standpoint by engineers in the design of consumer products such as automobiles, airplanes, and sports helmets. Because of the research background in the field of Biomechanics of Injury, there are now codes and standards that have quantitative assessment values. Although the HIC was initially developed for lateral impacts to the head, it has been used in other directionally applied loads. In this instance, it gives a representative measure of the magnitude of the accelerations loading to the head as it relates to probability of injury. The Head Injury Criterion often summarized as HIC provides a quantitative assessment of the acceleration pulse that the head experiences as a result an impact force to the head. It is represented as:

$$HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2 - t_1)$$

HIC Evaluation

In this case, the evaluation of the HIC value was done in cooperation with Michael Kravitz, PE, who has presented the development of the data necessary to obtain a quantitative assessment of the magnitude of the impact to the plaintiff's head. From this companion analysis and the additional analysis presented here, the merit of the claim of a significant and chronic (long-lasting) concussion was presented in the discovery process. The impact velocity of the top of the picture frame was calculated as compared to the opposing expert who modeled the picture frame as a falling stick of uniform cross-section, not incorporating the actual mass distribution of the picture frame. The erroneous model resulted in an excessively high impact velocity. Initially, the representation of the impact velocity was done by Michael Kravitz in the companion paper that indicates the impact velocity of the upper rail of the picture frame just prior to making contact with the top of the head of the injured party. The evaluation of the magnitude of the head injury criterion, HIC, was done with Mathcad, the representation shown below:

$$\tau 1 := .001, .002 .. .025 \qquad A_{adj} := 1., 1.1 .. 100.0$$

$$HICv(\tau 1, A_{adj}) := \left[\frac{1}{(\tau 1)}\cdot\int_0^{\tau 1} A_{adj}\cdot\sin\left(\frac{\pi\cdot t}{\tau 1}\right)dt\right]^{2.5}\cdot\tau 1$$

Mathcad formulization for HIC calculation

Here, the magnitude of the maximum acceleration is varied from zero to a maximum of 100 g's and the duration of the impact pulse is varied from 1 to 25 milliseconds. The actual impacts determined from experimental results are normally 4 to 8 milliseconds. In the case in point, the opposing expert used exaggerated accelerations and pulse times to calculate a HIC value that implied the injury was more severe than would have occurred had the values presented here been used. Figure 4 shows the contour plot of

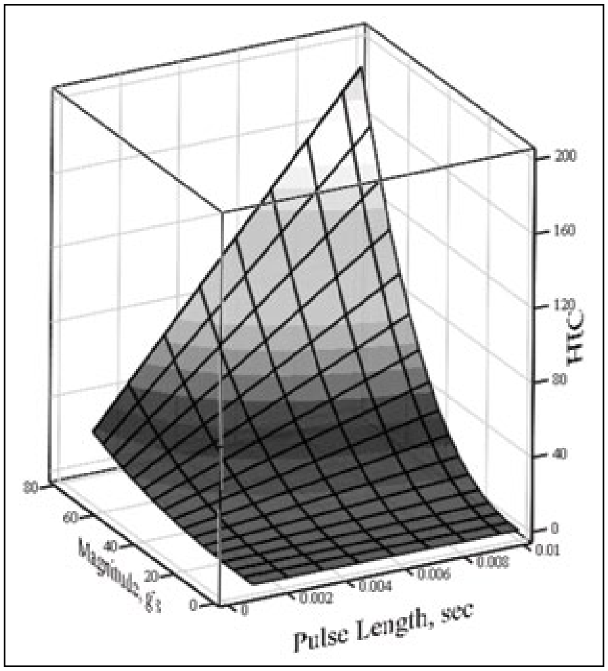

Figure 4
HIC for varying pulse length and head acceleration

pulse length and acceleration magnitude with HIC on the vertical axis. Experimental test results conducted with a falling exemplar picture frame and a Hybrid III head and neck produced head accelerations of 58 g's. This is a force of 580 lbs., and the calculated HIC value is 36 for pulse duration of 4.3 milliseconds. In the companion paper, Michael Kravitz calculated the range of neck dynamic constants giving a range of accelerations of 22 g's to 80 g's. These values yielded a range of HIC from 3 to 75.

The use of the acceleration value for the assessment of potential injury is often a basis for a claim that the injured party has suffered irreparable harm from an incident. However, current assessment methods for immediate evaluation of the of the existence of a concussion as is done in sporting contests, and the potential for recovery, is not often used in the exchange of arguments in a litigation setting. In this instance, there was no loss of consciousness and the subject only sought treatment after several hours of remaining in the social setting of the family Christmas Party. Figure 5 shows the recent concussion grading scales applied to evaluating the seriousness of a concussion and the likelihood of recovery.

In this instance, using data provided from the discovery documentation, the concussion in this case was more likely than not a grade 1. The arrows are added to show the diagnostic values used in the conclusions. Current studies that are being conducted for competitive sports that involve head impact have shown that there is duration to objective measurements of concussion and that these are shown to resolve within a reasonable period of time. When concussion scores are evaluated over a time period starting immediately after the concussion event and extend for up to the following 3 months, the greatest changes are seen to occur in 7 days, with the subject returning to nearly original baseline values within this time period. It is of interest that these studies have been conducted on competitive athletes who are motivated to return to play and are not attempting to malinger from their concussive event. In fact, this correlates with current observations of coaching procedures that will keep athletes with mild concussions out of play for a week before returning to competition.

Commonly, when reviewing information provided in head litigation matters, chronic cognitive loss is claimed as a result of the impact. These symptoms are often self-diagnosed and long-lasting. A similar assessment of cognitive function in conjunction with the data shown in Figure 6 is seen in Figure 7 where cognitive recovery is assessed over a 90 day period following a mild concussive event. For cognitive function, there is a similar time scale of recovery for this data.

Recent concussion grading scales

Guideline	Grade 1	Grade 2	Grade 3
Cantu [6]	1. No loss of consciousness 2. Posttraumatic amnesia lasts less than 30 minutes	1. Loss of consciousness lasts longer than 5 minutes OR 2. Posttraumatic amnesia lasts longer than 30 minutes	1. Loss of consciousness lasts longer than 5 minutes OR 2. Posttraumatic amnesia lasts longer than 24 hours
Colorado [23]	1. Confusion without amnesia 2. No loss of consciousness	1. Confusion with amnesia 2. No loss of consciousness	1. Loss of consciousness (of any duration)
American Academy of Neurology [1]	1. Transient confusion 2. No loss of consciousness 3. Concussion symptoms, mental status changes resolve in less than 5 minutes	1. Transient confusion 2. No loss of consciousness 3. Concussion symptoms, mental status change lasts longer than 15 minutes	1. Loss of consciousness (brief or prolonged)
Cantu [7]	1. No loss of consciousness OR 2. Posttraumatic amnesia, signs/symptoms last longer than 30 minutes	1. Loss of consciousness lasts less than 1 minute OR 2. Posttraumatic amnesia lasts longer than 30 minutes but less than 24 hours	1. Loss of consciousness lasts more than 1 minute OR 2. Posttraumatic amnesia lasts longer than 24 hours OR 3. Postconcussion signs or symptoms last longer than 7 days

Figure 5
Concussion Grading Scales

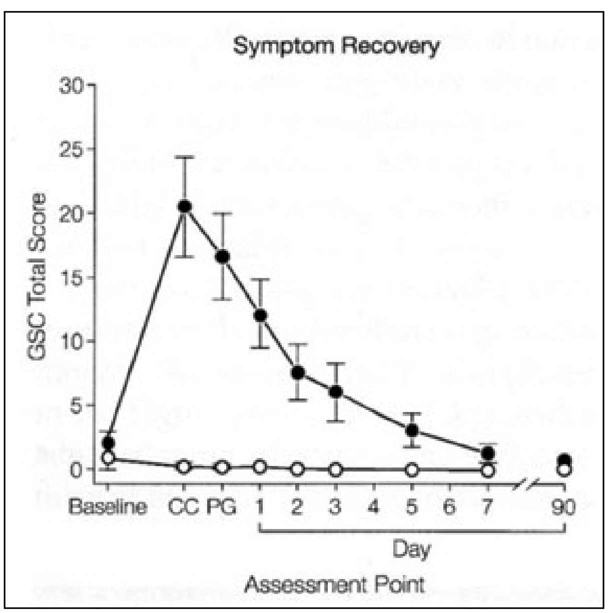

Figure 6
Symptom Recovery from Mild Concussion

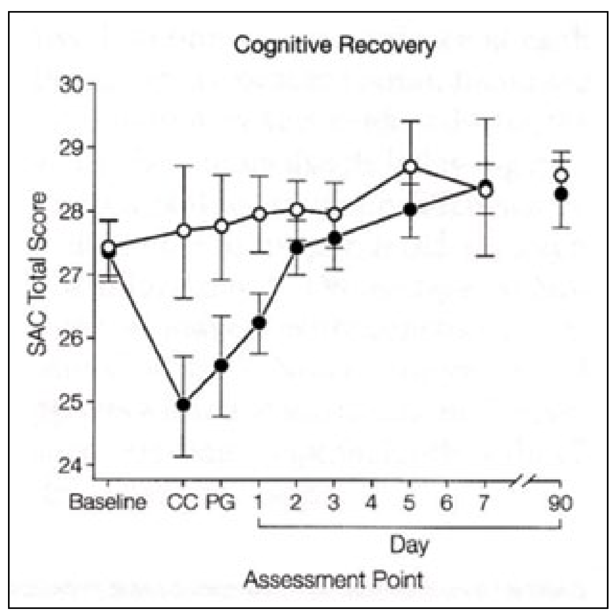

Figure 7
Cognitive Recovery from Mild Concussion

The claims that are often made relating to serious and long-lasting symptoms are difficult to defend because they often are self-referenced and are claimed to be life changing events. In addition to the actual calculation of the value of the HIC, there is also a risk assessment curve that equates the likelihood of injury with the HIC value that is calculated. The Abbreviated Injury Scale (AIS©) is an anatomically-based, consensus-derived global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale (1=minor and 6=maximal). It has been developed and maintained by the Association for the Advancement of Automotive Medicine. AIS 1 is classified as minor and AIS 2 is moderate. The explanation for AIS 2 is: *"cerebral injury with/without skull fracture, less than 15 minutes unconsciousness, no post-traumatic amnesia."* The Prasad-Mertz curve provides a probable likelihood that a serious injury did in fact occur. The Abbreviated Injury Scale (AIS) 2 calculation in Figure 8 shows the probability of AIS 2 for HIC values less than 200. There are other risk curves for other body regions and trauma assessments.

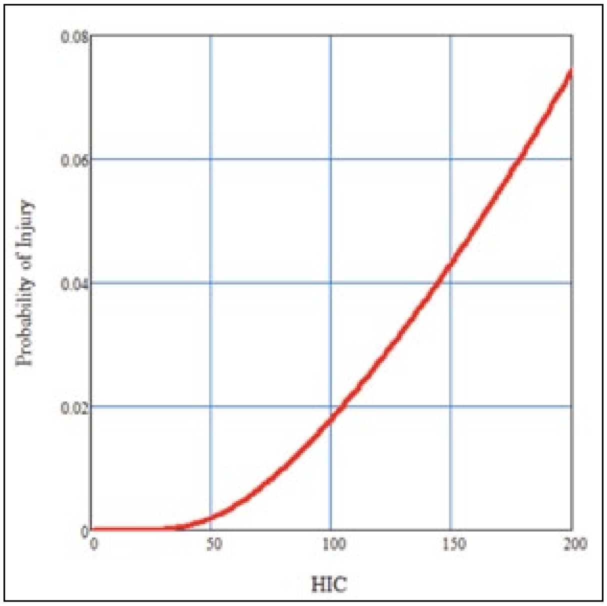

Figure 8
Probability of AIS 2 Head Injury vs. HIC
(Prasad-Mertz)

In the case here, the highest value of HIC was calculated to be about 75 if the picture frame fell directly on top of the subject's head. The experimental value of HIC was 33 with a Hybrid III dummy head and neck. In this case with a HIC of 75, the calculated maximum probability of injury would be 0.8%. For the test results with a HIC of 33, the probability of injury would be 0.02%. If the impact was not directly to the top of her head, or her head was tilted, the HIC value would be less. For common legal conclusion that requires a more probable than not criteria (50%), the likelihood that the subject received a serious concussion was not likely.

3. Cervical Neck Injury

The injury to the spine as a result of impact accidents, a contact to the head in this case, or a rapid acceleration incident such as an automobile collision, often results in a claim of spinal injury. This can involve the vertebrae, discs, ligaments, or the nerves within and emanating from the spinal column. In this instance, no objective findings were found at the time of the initial Emergency Room visit on the night of the accident. Upon the subject returning to her home in another city however, and after consulting with several physicians, one diagnosed and treated three cervical discs that were claimed to have been injured as a result of this head impact from the picture frame. In this instance, the subject was over 50 years old and had noticeable pre-existing osteophyte growth on the cervical vertebrae that occurred over a time period of many years prior to the accident. Figure 9 shows a pictorial representation of the graded normal aging progression of the spine.

The normal aging process for the spinal elements begins with the local degeneration of a disc, prior to any involvement with the adjoining vertebrae. As is shown in the lower portion of Figure 9, the growth of osteophytes occurs after the discs have begun to degenerate as a consequence of the normal aging process. When this starts and how rapidly it progresses is variable from person to person. In litigation, the diagnosed damaged disc is commonly claimed to have been caused from single impact load event, and the interested parties, having no historical data to base their assessment on, are led to a process defending the single event hypothesis. Figure 10 shows the basic spinal element under compression with the disc interposed between two vertebrae.

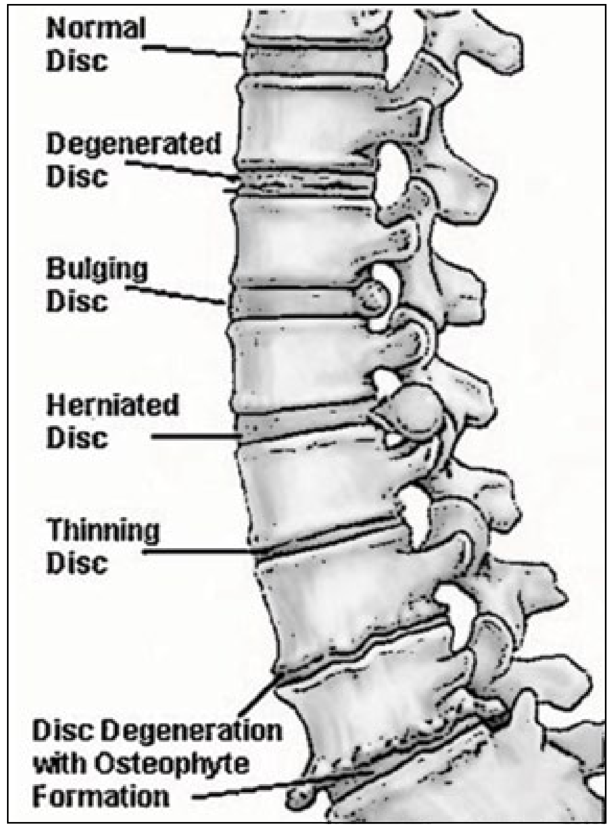

Figure 9
Progressive Pathology of Spinal Elements

In the commonly claimed scenario, the vertebrae is assumed to be a hard, strong, bony element and the disc a spongy unit described as a jelly donut with a soft center and fibrous outer ring. However, the loading and strength of the vertebrae-disc unit is not so simple. The center of the vertebrae are not a rigid as the outer enclosure, and the center spongy core of the disc produces a hydrodynamic load that causes a fracture of the vertebrae from internal pressure. Figure 11 shows these load paths is a diagrammetric manner.

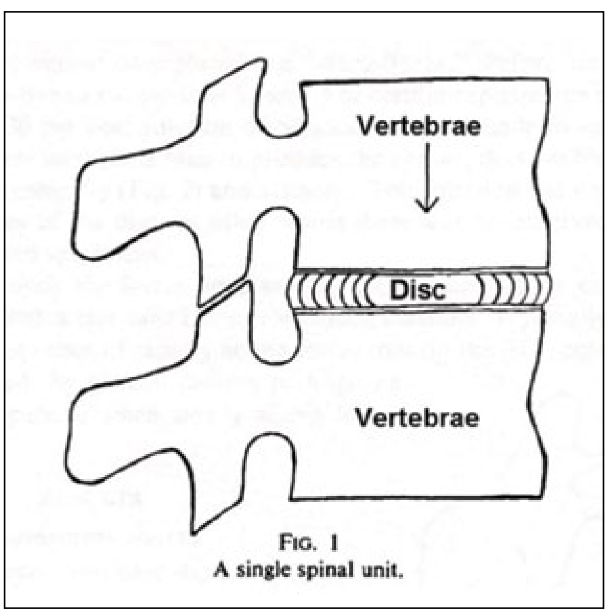

Figure 10
Basic Single Vertebral Unit

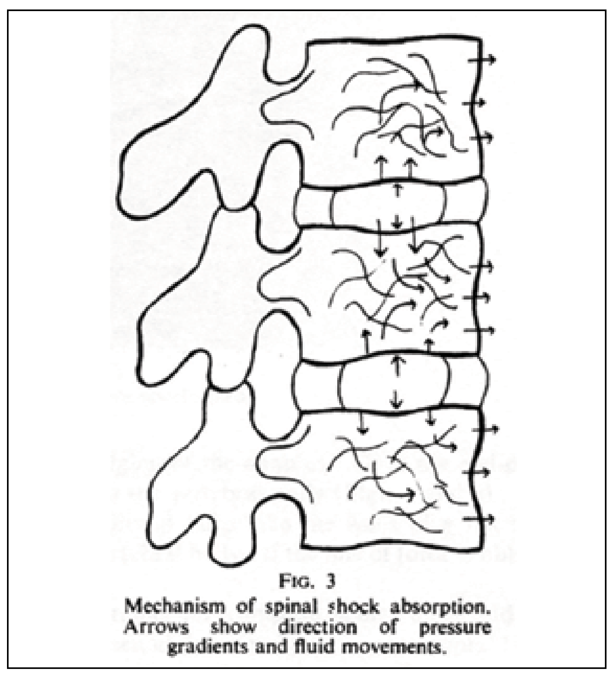

Figure 11
Loading of the Spinal Column

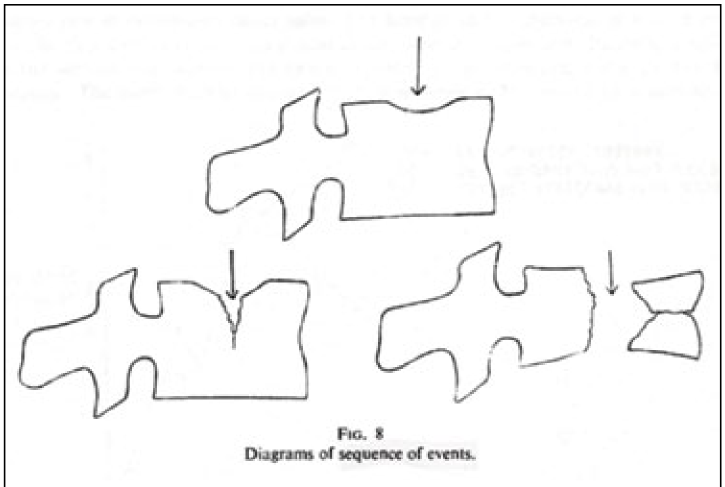

Figure 12
Failure Sequence of Vertebrae from axial loading

The loading of the spinal column with the stacked vertebrae and discs creates a large central pressure in the vertebral bodies, and the failure is from the inner structure of the vertebrae to apparently blow apart from internal pressure. Figure 12 shows how this loading causes failure from direct axial loading.

In this process, the discs are not initially damaged as the vertebral bodies are the weak link in the chain. Yet the claim is commonly made that the discs are the most vulnerable and the bony vertebrae are the strongest unit, remaining undamaged in the loading process. The current research on spinal loading failure is showing that; "Compression forces are mainly absorbed by the vertebral body. The nucleus pulpous, being liquid, is incompressible. The tense annulus bulges very little. On compression the vertebral end-plate bulges……The normal disc is very resistant to compression. The vertebral body always breaks away before the normal disc gives way….The vertebral end-plate bulges and then breaks, leading to vertebral fracture." Yet, in this case, the treating physician testified , since he had the imprimatur of being a medical doctor," a 50 pound painting strikes you on your head…..it can cause subluxations and disc herniations." A recent publication stated: "…injuries to the intervertebral discs were only observed in specimens that sustained severe vertebral body fractures." (Duma 2008)

4. Dental Fractures

The subject also claimed that as a consequence of the impact to the head, she sustained several dental fractures, and she also alleged that she briefly suffered from Temporomandibular Joint tenderness. Figure 13 shows the line of force from a biting force as referred to the TMJ condyle (pivot joint).

From a central view looking at the range of biting forces, the normal biting forces from the teeth are shown in Figure 14.

A calculation of the tooth loading resulting from the acceleration of the mandible that weighs approximately 1 pound could produce a load on a single tooth. This is shown in Figure 15.

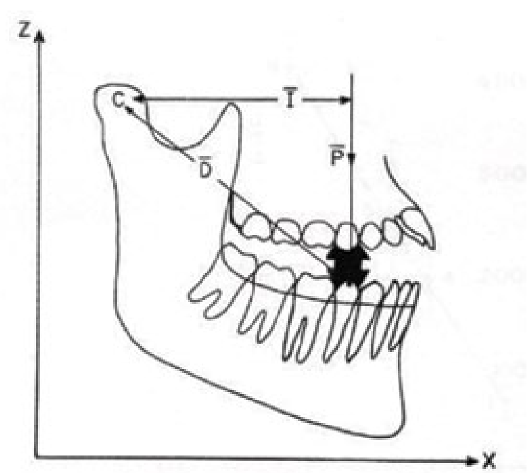

FIG 2.—Tracing shows direction and line of action of average maximum biting force ($\bar{P}$), average moment arm ($\bar{T}$), and average distance ($\bar{D}$) between center of occlusal surface and center of condyle for second premolar position (5).

Figure 13
Biting Force reference diagram

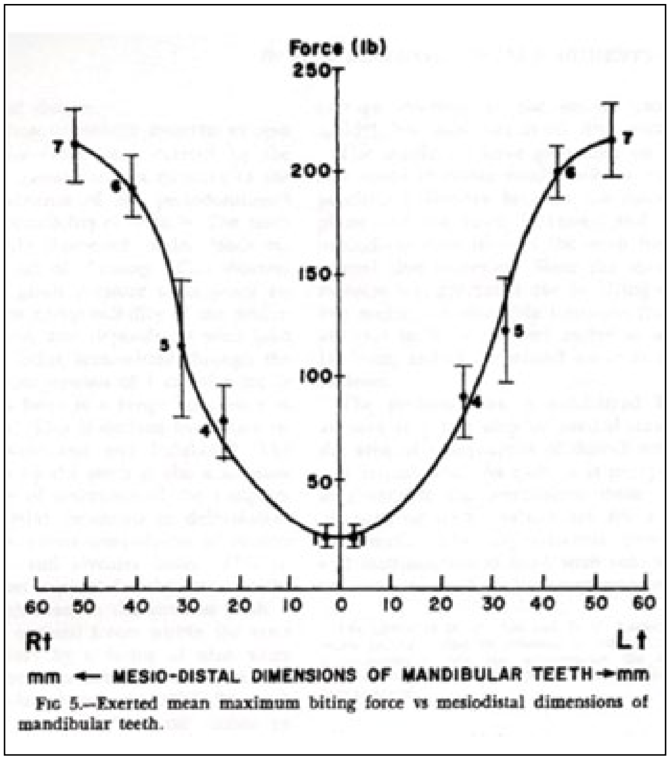

Figure 14
Normal Biting Force Distribution

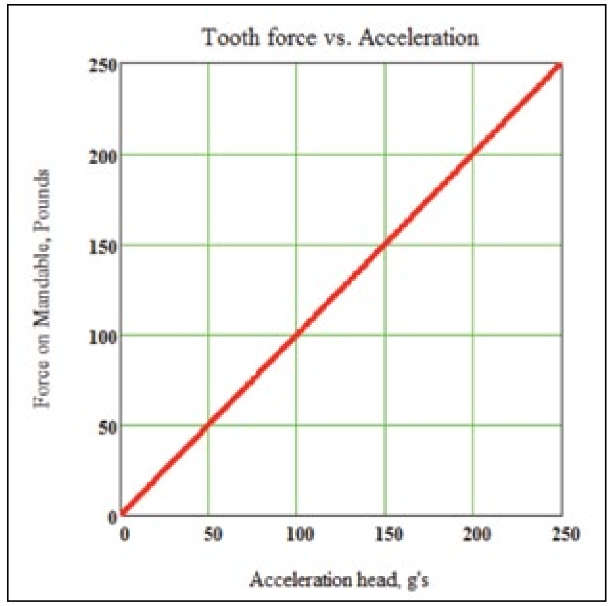

Figure 15
Single tooth load from acceleration of Mandible

The subject claimed multiple tooth fractures as a result of this acceleration event to her head as a result of the blow to the top of her head. It would appear that the normal biting forces would exceed the acceleration forces from the accident.

Conclusions

This case was concluded with the settlement by the defense attorneys for the hotel chain. Although the biomechanical evaluation indicated that the degree to which the plaintiff claimed she had been injured was doubtful, the intervention of the treating orthopedic surgeon who replaced two cervical discs and fused a third indicated that she had undergone a serious medical procedure was not challenged. The laceration to her head had healed and was never mentioned. The cognitive defect was claimed but only self-diagnosed and no objective data was available. Her tooth fractures were claimed although she had a long history of serious dental trauma. But finally it was the treatment by the orthopedic surgeon that was persuasive that resulted in motivating settlement.

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