9 Head and Neck Injuries in LTV Rollovers

and

What to Do About it!

by

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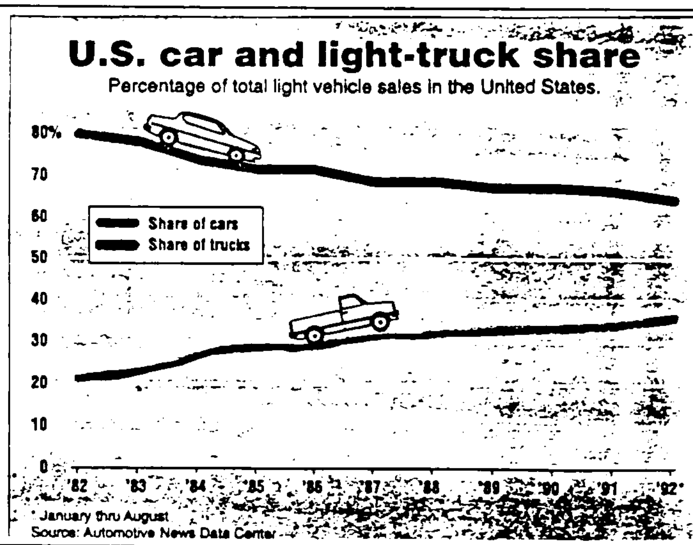
This is a follow-up to our paper "Roof Collapse and The Risk of Severe Head and Neck Injury." The focus here will be to deal more broadly with the types, causes and countermeasures to injuries in rollovers, and also to describe some differences between Light Truck and Van (LTV) and Auto rollovers. We will briefly cover:

1. Accident Statistics,
2. Real World Case Studies,
3. Example Case Summary Analysis
4. Experimental and Real World Rollover Differences,
5. Countermeasures or What to do about rollovers.

I. LTV vs. Auto Accident Statistics and Analysis

1. LTV's are the fastest growing segment in the market. The following chart plots the rise of market share of LTV's relative to autos since 1970.

AUTO AND LTV ON MARKET SHARE



2. LTV Rollover rates are 3 times auto rates.

3. LTV Fatality rates in rollovers are twice those of autos.

4. More than 2500 annual LTV rollover fatalities and

5. More than 5000 annual LTV permanently disabling injuries.

6. 19% of LTV HARM comes from roof and roof support contact.

II. Real World Case Studies

A. Since about 1977, the U.S. auto industry has been claiming that in rollovers, roof crush is unrelated to head and neck injuries and that stronger roofs, better belts, padding or other safety features will not mitigate such injuries.

B. We have investigated and analyzed more than 10 such LTV rollovers in excruciating detail in accordance with the protocol of the 1989 Live Subject Safety Research paper. While NASS teams spend less than 40 hours/case, our scientific Accident and Injury Reconstruction involves more than 200 professional hours each and includes computer validation of vehicle trajectory, occupant kinematics, injury mechanisms, and potential countermeasures.

EXAMPLES OF LTV CASE STUDIES

	YEAR	VEHICLE	INJURY	STATE
1.	1987	GM Astrovan	Quadriplegia	CA
2.	1983	GM S-10 Blazer	Fatal	PA
3.	1987	GM S-10 Blazer	Quadriplegia	UT
4.	1988	GM P/U 2500	Quadriplegia	WI
5.	1981	Ford F150 P/U	Brain Damage	AK
6.	1985	Suzuki Samurai	Quadriplegia	NJ
7.	1985	Jeep Cherokee	Fatal	FL
8.	1985	GM Sierra P/U	Quadriplegia	AZ
9.	1991	Ford Aerostar	Quadriplegia	CA
10.	1973	GM Sierra P/U	Quadriplegia	TX

C. We have found and scientifically proved that in most cases, the severe injury is the result of some combination of structural and restraint defects, easily CORRECTABLE with well known, available and developed technology. Frequently we have identified and found proof of the defects by comparison with others in the same accident who are uninjured (or less severely injured.)

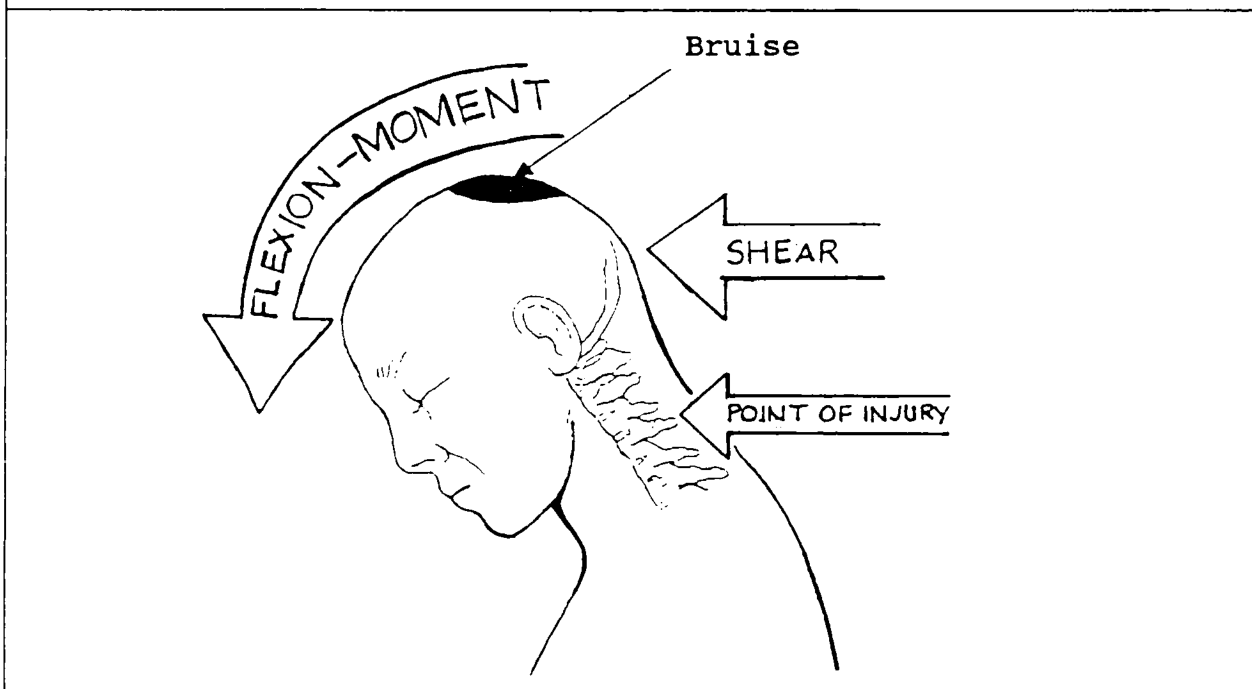
D. Invariably, effectively restrained occupants who do not violently contact interior surfaces are less seriously injured than those occupants who are unrestrained.

E. Our objective is to demonstrate that simple improvements to existing safety systems, most, already in limited production, would grossly reduce casualties if more universally applied.

III. Example Case Summary Analysis

A belted driver rolls over in a new full size pick-up truck resulting in quadriplegia from spinal cord transection at C4, C5 with bilateral locked facets and posterior ligamentary disruption. The treating physician, a neurosurgeon and biomechanics researcher described a blow to the head (and a large hematoma) at the bald spot resulting in a frequently occurring hyperflexion with some compression and shear.

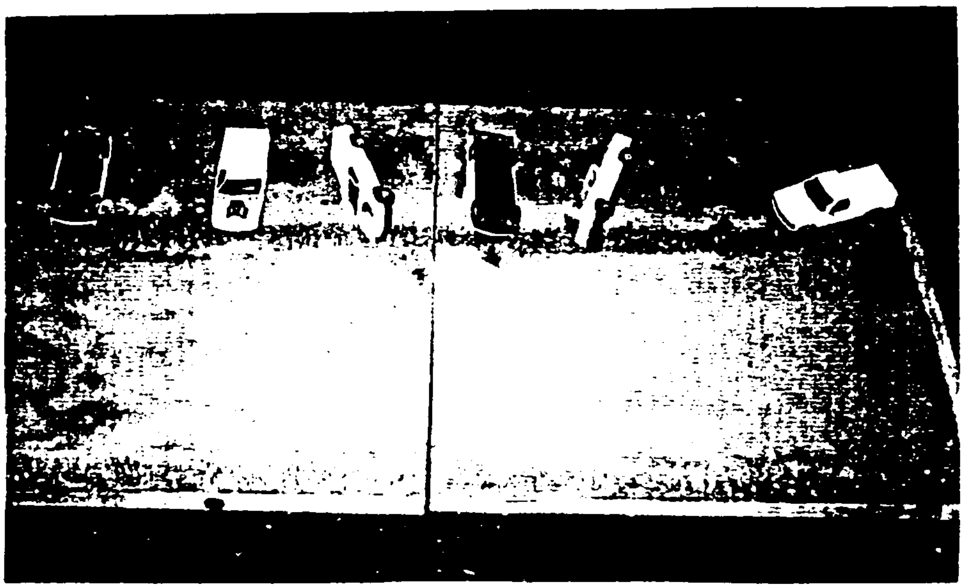
NECK INJURY



Accident Reconstruction

There was sufficient physical evidence and documentation at the scene such that there was little uncertainty about the sequence and the time history of vehicle motions, velocity and structural deformation. That sequence went as follows:

ROLLOVER SEQUENCE



a. a violent left yaw, with a right front wheel trip at about 30 mph,

b. a wobbling spiral first roll with right A pillar lateral collapse resulting in 6 to 10 inches of leftward and rearward displacement of the roof rail and roof

c. followed by a lateral roll and roof impact collapsing the left A and B pillars vertically by more than 10 inches at which the injuryy occurs,

d. ending with 19" of residual roof crush.

PICK-UP COMPARISON

Occupant Kinematics and Injury Mechanics

We modelled in 3-D, the vehicle trajectory and 200 degree/second roll with a correctly sized, restrained driver, and located his position in the cab at the 1 and 1/2 roll touchdown and vertical roof collapse as: torso leaning forward and to the right, head flexed, hands on wheel, hanging in the lap belt with about 50 pounds of erecting (roofward and outward) centrifugal force. The positioning was confirmed by a witness mark on the roof liner and roof, as to the head to roof contact location.

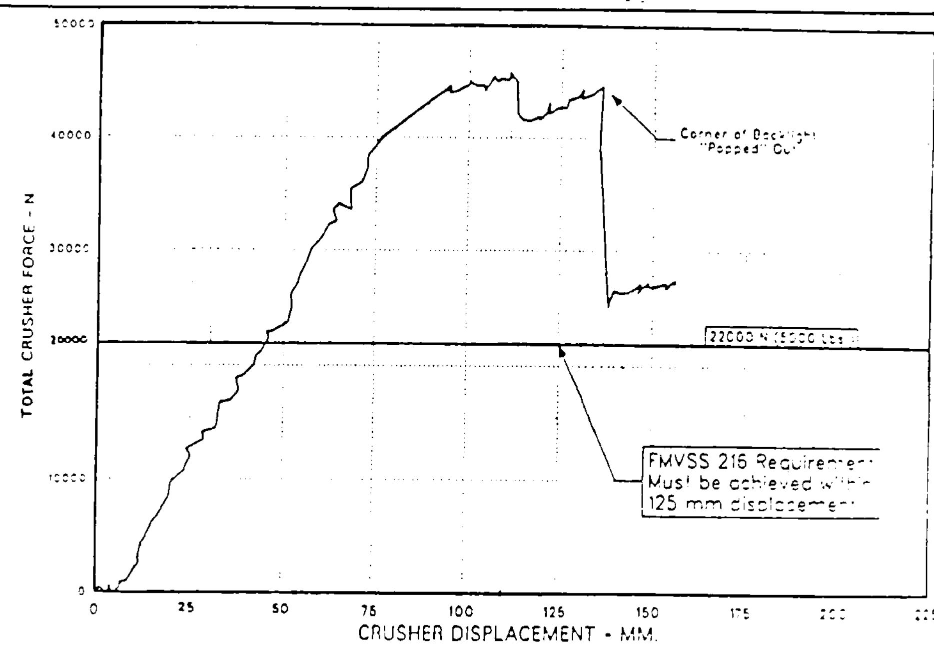
We then parametrically modelled in 3-D thirty nine various combinations of initial position, roof deformation extent, belt slack, torso augmentation velocity, etc. to estimate the injury mechanism characteristics.

Defects and Countermeasures

Having narrowed the range of uncertainty about the parameters of the injury mechanism, we modelled alternative designs for the structure, restraint and padding. The results indicated the following defects, which if corrected would have avoided the injury:

a. Although the vehicle roof structure was 50% stronger than the competition in static (FMVSS 216 type) tests because of a bonded backlight and windshield, this advantage was lost almost instantly in the rollover, when the glazing cracked.

FMVSS 216 TEST RESULTS ON CK 2500 TRUCK



b. There was inadequate air gap padding in the roof rail structure with a 5/8" separated two panel roof.

c. The two spool retractor harness with comfort feature restraint system, allowed the occupant 4" to 6" of excursion toward the roof, using up the available headroom.

We then demonstrated, with the most probable accident and injury reconstruction, that correcting these defects avoided the injury.

IV. Experimental and Real World Rollover Differences

Experimental rollover tests have evaluated the potential for axial neck compression injury, an infrequently occurring injury mechanism. Nevertheless, the Malibu II tests show that:

1. In the production cars, there were about two axial neck compression injuries per dummy per test.

2. There are ten axial compression driver injuries in crushing roof production cars to two in rollcaged roof cars. Therefore, the risk of such injury is 5 times greater in production than rollcaged cars.

3. The roll rate is 400 to 500 degrees per second (to move the dummies outward and upward with more than 200 pounds of centrifugal force).

4. There are only two injuries from excessive flexion moment - with some shear and compression - in the Malibu series, both occurring under the most severe roof crush portion of the production vehicle rollovers. None in the rollcaged vehicles.

MALIBU II ROOF CRUSH WITH FLEXION/SHEAR/COMPRESSION INJURY

5. Photographic analysis and electronic instrumentation shows Roof Crush begins well before even axial compression injury.

In real world rollover accidents:

1. Less than 5% of the rollovers result in severe head and neck injury. That's 1 injury in 20 rollovers.

2. Most rollover accidents are preceded by a violent change in direction (yaw) displacing the occupants forward and laterally from their normal seated positions (and out of the shoulder belt).

3. The occupant's bent forward and lateral position is maintained by opposite side vehicle to ground contacts and the low centrifugal forces.

4. The resulting trip and roll rate are often in the 200 degree per second range producing low centrifugal forces, so outward and upward motion is easily overcome by occupant's reaction

5. Rarely is a real world neck injury an axial neck compression. Generally speaking God designed the neck to flex or bend under load, and injury most frequently occurs when the neck bends too far.

6. Even current restraint systems are effective in preventing neck bending injuries in LTV's without significant roof crush because the torso motion between occupant and roof must be something like ten inches.

V. Countermeasures or What to do about it!

Accident Avoidance -

Certainly we need:

1. to control roll propensity.

2. Anti Lock Braking Systems.

3. to start dealing with LTV's as passenger vehicles and provide the best in protection considering the increased risk over cars.

4. to warn drivers that LTV's don't handle like cars.

5. to warn that advertisers use professional drivers to operate LTV's at their off road limits.

Crashworthiness -

There are also a variety of simple, practical and economical countermeasures which will work to keep the roof from collapsing, to keep the occupant away from roof contact and to mitigate the consequences of contact. These are:

Structure -

The forces of roof rail to ground contact on an LTV vehicle in which the roll radius is 15" less than the CG to roof rail distance easily exceeds FMVSS 216 roof strength.

The lateral forces which are applied to the roof in an LTV rollover require a revised FMVSS 216 test. Perhaps to apply platen forces at 40 degrees from the horizontal for 5 inches and then at the conventional 75 degrees for 5".

The key then is to brace the roof support structure to limit dynamic deformation to 4" at up to 40,000 pounds. We believe finite element analysis can accomplish this at a cost in the order of ten pounds per side of metallic cross bracing and the elimination of voids and holes.

Previous developments include:

- a structural composite foam to fill and stiffen roof support pillars much like the Minicars RSV.

- wider vehicles with a monocoque roof shape and structure, inboard seats and more head room.

- more pillars, larger pillar sections, heavier gauge metal, cross sectional transverse webs.

- cab forward, lower height windshields with bigger headers and A pillar supports

- cross members that do not fracture and pillars that do not buckle and collapse.

Restraint -

The lap belt assembly must include a tensioning device which eliminates the slack by sensing pre-trip yawing acceleration and spools up webbing at a force level of perhaps 25 pounds. Such wind-up forces may be stored by belt extension as it is applied for use or by hydraulic pressure. At least slack can be minimized by an automatic locking lap belt restraint system.

Anchor points located and integrated into the seat for better fit independent of body size or seat location and retractor pre-tensioning.

Padding -

In 1967, GM and Ford developed metal air gap padding 2" thick, as a means of limiting the forces on head contact at velocities to 15 mph and applied it to the roof support pillars in 1968 to 1972 vehicles.

In 1972, it was employed in the roof and pillars of the GM Experimental Safety Vehicle as a means of head impact protection.

It is our contention that two inches of four hundred pound force limited metal air gap padding can significantly reduce the probability of excessive compression loading of the neck between head and torso in rollovers.

Such force limiting may also be employed to absorb and arrest some torso energy while belt restraints stretch to full effectiveness in stopping the torso, all without exceeding the head to torso, neck compression, cervical spine injury criteria force level.

Apparently, this concept is difficult to grasp because of preoccupation with an experimental "drop test" procedure. A rollover cannot be characterized by a drop test, because the drop test involves vertical not rolling motion.

The experiments of which we are aware have a virtually unrestrained upside down occupant whose head is close to the roof or padding which is then in contact with a rigid surface. As a result, experimenters believe that torso augmentation drives the neck into the head stopped by foam, and continues to do so until all the energy is removed from the torso.

Consider the real world auto rollover case. The vehicle is rolling at 400 degrees per second and, with a rigid roof rail, remains in contact with the earth for approximately 10 ms at 15 g's, as demonstrated by the B post acceleration records of rollcaged vehicles, before moving on.

During that 10 ms, a typical occupant velocity toward the roof may be 100 inches/sec. So the occupant moves about 1" towards the roof during that 10 ms. Now, if the head is in contact with the roof (and Ground) at the beginning of that event, the occupant will experience an axial neck injury. But, if the head is in contact with an angled, force limited metal air gap surface (padding) at least two inches thick, it will deform and bend the neck at force levels below injury producing levels as shown below.

UNPADDED AND PADDED HEAD TO ROOF CONTACT AND NECK INJURY		
DESCRIPTION	**RUN# 244**	**RUN# 247**
Run Description	Inverted 180°	Inverted 180°
Occupant Joint Type	Human	Human
ROOF Motion	10"	10"
Initial Occ. Vel.	80"/sec	80"/sec
Vehicle Motion	Lateral Roll	Lateral Roll
Occ. Initial Orient.	Leaned Forward	Leaned Forward
Belt Attachment Type	Limited Pitch	Limited Pitch
Belt Slack Represented	Pretensioned	Pretensioned
PADDING	As Designed	2" Force Limited
Neck Load "Z" (lbs.)	-1274 @ 45 ms	-593 @ 35 ms
Neck Moment Flexion (in-lbs.)	+258 @ 90 ms	+346 @ 95 ms
Head to ROOF Contact (inches and pounds)	2.6 & 1568 @ 50 ms	3.1 & 1310 @ 55 ms
Neck Pitch Angle (°)	-20 -> -84.3	-20 -> -86.6

DISCUSSION

PAPER: **Head and Neck Injuries In LTV Rollovers and What To Do About It**

PRESENTER: Donald Friedman

QUESTION: Roger Nightingale, Duke University

We've done some work recently where we've used padding in some cadaver impact tests and we found that padding can, in some cases, enhance the risk for neck injury by entrapping the head. Do you have any comments about that?

ANSWER: Yes. I think that is certainly the case and so it's very important to use the right kind of padding. I think the idea of the metalized padding is to avoid that and it's also the case that what you want to do is cause the neck to bend. That's the way God intended it and you don't want to deal with it solely as an axial compression. That is, you'd like the surfaces to be inclined to the direction of travel of the head, neck and torso.

Q: Guy Nusholtz, Chrysler Corporation

Do you have any experimental justifications for any of the suggestions that you made or are they primarily conjectural?

A: Well, I think the GM ESV actually did a roll test, a rollover, and they also did a three foot drop test, I think on the roof. No. I would say all of our experimental justification is through computer simulation and through comparison with litigation testing.

Q: What type of computer simulation?

A: We use the CVS, ATB 3D Program and we do a variety of things. One is to consider the whole issue of the rollover as a rollover to identify the position of the occupant at impact, or at the point at which we believe the injury occurs, so you identify his initial position and then we do a parametric analysis using the same ATB to consider the variety of alternatives because you can't identify the explicit factors that carefully, so you take half a dozen of the variables, what you consider the nominal and on either side of the nominal and see if you can narrow the range and when you do, what we find is that padding works to a degree, restraint systems work to a degree and keeping the roof from collapsing is the most important single factor when you are dealing with an injury that is a flexion kind of injury. When you are dealing with an axial compression injury, keeping the head off the roof and the padding is the most significant way to deal with the problem, but I want to emphasize again, it's keeping the roof from collapsing, not from deforming. A couple of, three, four inches of deformation does not appear to be the issue. The collapse of the roof like ten inches or so with a reasonable amount of headroom and a reasonable size person and a flexion injury, it takes like ten inches of roof collapse to cause the kind of injury that Keith was showing you. You can't really address structural issues with a CVS Program. They are not part of the code. You fake things, fake structure in the CVS so it's very difficult to imagine that you would get anything out of it because, with doing that, you could basically make the CVS give you any result that you wanted. Second point is, I've also done a lot of testing with padding and either, as Roger said, is counter-indicated or it doesn't do anything, so padding in itself does not help, particularly for compression injuries unless you are talking about four to six inches of padding.

Q: Thank you.

Q: Tony Sancer, Medical College of Wisconsin
Don, what were your proposed studies, the tests, did you want to do two tests to evaluate the structural integrity of the vehicles?

A: Well, I think that the problem is how to, in terms of LTV's, how do you duplicate a roof crush situation as compared to automobiles? In automobiles, we use the 216 test, which is a 75 degree force from a platen onto the roof structure. I think because of the configuration of pickup trucks, you need to provide a lateral force, something like 40 degrees to the horizontal, that pushes the roof sideways and then to apply a vertical force, because in the sequence of impacts that's what it appears occurs with the studies of the vehicles that we have done.

Q: It's pretty clear dynamically when a vehicle rolls that you have a lateral because that's what really happens and that's what pushes the roof over the lateral force that we have. I think that's a very good suggestion. The other thing is we have done studies to look at levels of force on plates with padding and so forth and to look at HIC and certainly, as you increase the padding, those values are reduced.

A: Yes. But I think that contrary to what Guy has said. The CVS Program, in fact, does allow you to model the deformation of the roof or any other structure as an equivalent pulse to the pulse of the vehicle and, if you do it from a parametric point of view, you are dealing with a set of circumstances in which you can then change the pulse that causes the roof deformation and see the effect of varying degrees of roof deformation parametrically on a fixed situation, as well as changing the effects of the slack in the belt or in the vertical velocity of the occupant, and that's the kind of thing that we have done. We typically do a parametric analysis that consists of about 39 individual tests that narrow the range and, as far as we can tell, padding does help if you limit the force to the levels that are suggested as neck compression limits, because torso workmentation doesn't have as much energy as you might think when you have belts that have a reasonably small amount of slack.

Q: T. C. Low, Ford Motor Company
I have very little experience with the CVS program. For your modeling, how do you try to simulate the structure? What is a typical roof shape and time duration in trying to simulate the structure of the vehicle.

A: Well, what usually happens is that we get a litigation test of the structure in a rollover and you can model the way that the roof collapses by doing a photographic time simulation of the displacement and then you put that in as the pulse for the roof crush.

Q: Jim McElhaney, Duke University

We've been doing cadaver tests and simulations of cadaver head and necks with the torso mass and dropping these surrogates 2 feet velocities of 8 to 10 feet per second. We get significant neck injuries of a variety of types. We find that padding does not do very much of anything in terms of protecting the neck under these circumstances. We have in one of our preparations, a six-axis load cell at the base of the neck and then measure also on the three-axis load cell, the force is on the head and what we find there is that there is a phasing between the pulses that the head strikes the padding and stops. The torso then continues moving and the neck has to stop the torso and under these circumstances, the padding does not significantly affect the forces on the neck. In addition, the padding does something, and particularly if the impact angle is not perpendicular to the plate, and that is, it traps the head and allows then the neck to more easily be loaded by the torso, so I think the question of the padding is a very complex one and needs to be studied very carefully because we may wind up doing something that our intuition and certain computer programs tell us is right, but in fact may cause a lot more neck injuries than anything.

A: I agree with you, Jim. I think though that some of the work that you did indicates that most of the kinds of injuries that we deal with are not compression injuries, that they are flexion injuries and if you're talking about tests with unrestrained occupants, then you are not taking into account the energy reduction effects of the belts if the belts are, in fact, tight enough to allow or to keep the head from impacting the roof with very much distance of between the first contact and the end of the energy absorption phase. So, I'm talking about force limiting padding of the metalized type.

Q: Barry Myers, Duke University

I feel a need to respond to this in that you're missing the point. The padding at the head does nothing to stop the torso. It stops the head. Because the neck is a relatively compliant structure, the head and neck are decoupled initially. So the head hits the padding and stops. Now, I've never seen a foam that doesn't pocket to some extent and I don't know how you can tell that from a computer program.

A: Yes, well we're not talking about foam.

Q: So, the foam stops the head. The torso can have very little velocity and break the neck regardless of the initial position of the head and neck, regardless of the orientation, regardless of whether you classify it as flexion or compression. Very little torso velocity can break a neck and I don't think you can see that in these simulations.

A: Well, I think we can and we do. The point that I would make is that we're not talking about foam. We're talking about forced, limited, metalized padding with an air gap inside and the issue of the heads stopping is that the head doesn't stop. The head continues but limits the maximum force between the torso, the head and the neck to some value associated with its force-limiting value and when it bottoms, it's over. No argument but if you have enough force limiting material, like two inches of head depth and you have belting, belts are effective and that two inches is enough.

Q: It's hard to imagine that you can reduce the torso velocity so greatly. If the foam is two inches tall, then it's going to bottom out at say an inch or half an inch.

A: But you keep saying "foam." Why do you say "foam"? I'm talking about air gap padding.

Q: It's forced limiting metalized material?

A: Yes.

Q: Sooner or later it's going to bottom out and if you are saying it's two inches thick, then it will probably bottom out at say, an inch.

A: Why would it bottom out at an inch?

Q: Sooner or later it's got to bottom out.

A: I agree that when it bottoms out it's the end.

Q: It doesn't deform? You have this material that deforms at a constant force and sooner or later, it stops and if it is say, two inches thick, it is going to stop at say an inch or an inch and a half of deformation. So in that inch and a half of deformation, you have to really stop the torso and it's hard to imagine that you can see that level of resolution from very simple computational models. The problems are just too complex and non-linear to do that and that's really my final point.

A: Yes, and I do agree, but the question of this inch and a half, you are assuming that the torso has to be stopped by the padding. What I'm saying is that the torso gets stopped by the belt and the last inch and a half is a bonus that you get from the padding.

Q: I'm not assuming that the foam stops the torso. I'm explicitly telling you the foam doesn't stop the torso, and that's what we've learned.

A: I agree.

Q: You are saying that you can stop the torso at an inch and a half and that somehow this padding is going to make a difference.
I understand what your goal is to stop the torso but I still don't know what this foam is doing to protect the neck.

Q: Just a statement. First, force is not a good indicator of neck injury and you cannot simulate the structure of the neck with a CVS to say whether it is injured or not so using a CVS to determine whether foam is going to cause an injury is invalid.

A: Yes, I understand that. Has anybody done a cadaver experiment in which there has been two inches of metal air-gap padding, a restraint system which allows the head and neck to reach the material but not to go much beyond it. If you had such a test then I would agree that you duplicate our simulations.

Q: I'm starting to understand what you're saying. As I understand, what you're saying is, "we are going to have a belt system that stops the torso at the same time that the foam stops the head" and that's going to work for the full range of ampipometrics that people have, long and short necks, different shaped heads.

A: No, I don't think that's the case. I think that what is the case that if you have an effective restraint system, you are going to keep the head from the roof if you have enough headroom and if you have an axial compression kind of injury, then the air-gap padding will limit the force in the last inch or two and that is useful, but there is no doubt that keeping the head away from the roof is the right thing. It is just that if you want to argue that, well, it can be no roof crush, then I think you need the padding.