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METHODS FOR AN INVESTIGATION OF 'WHIPLASH' INJURY

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BACKGROUND

This report describes a component of a collaborative project between the Department of Safety Science, University of New South Wales, and the Discipline of Anatomy, University of Newcastle. To elicit criticism and to ensure that the proposed project would provide the research community with useful data, the methodology of this research programme is presented. Published research in the area of trauma biomechanics is moving away from accident investigation and experimentation to numerical modelling. However, there is still a vast amount of information that is unknown regarding injury biomechanics and associated material properties. Materials and opportunities for conducting biodynamic research are scarce and it is the author's opinion that great efforts should be made, prior to embarking on an extensive test programme, to ensure that tile results can be fully exploited by fellow researchers. In this project 'whiplash' injury and spinal biomechanics are explored.

The incidence of 'whiplash' injury is high in most developed countries. Evans (1992) estimated that In the USA there were 1 million cases of 'whiplash' per year. In NSW the Motor Accidents Authority reported in 1994 (MAA 1994) that 'whiplash' was one of the injuries reported in 5000 annual claims, and in 1800 of these claims 'whiplash' was the only injury claimed. The average cost per claim was $AUS 12,000.

The unfortunate aspect of these reports is that there is no objective diagnosis for 'whiplash' injury. The diagnosis is always event specific, i.e. neck pain associated with a motor vehicle accident. Many structures could be injured during 'whiplash' e.g. the facet joints, the cervical discs, the ligamentous structures, spinal musculature the vertebrae or the brain. Unfortunately, it is difficult to assess these injuries clinically, even with modern imaging techniques. Furthermore, different injury mechanisms could be involved depending on the individual and the initial conditions, e.g. head orientation, impact direction and severity. At present causal relationships and injury criteria have not been developed. As a result the potential exists for further research to help define 'whiplash' injury and examine injury mechanisms.

A similar presentation was made at IE-Aust Biomechanics of Neck Injury Seminar, Adelaide April 1995, entitled 'A Report on a Programme to Investigate Whiplash Injury A Mechanisims'.

The aim of the UNSW research programme is to investigate the mechanisms of 'whiplash' injury and establish causal relationships from which neck injury and tolerance criteria can be developed. As only preliminary results are available the paper describes the theoretical and experimental basis for the current programme.

SUMMARY OF RELATED RESEARCH

In comparison to pure axial loadings (Z direction/vertical) for ejection seat development, or inertial loadings in the -X direction for frontal impact assessment, little research has been undertaken for +X inertial head/neck loadings. With regards to the global motion of the cervical spine, a frequently repeated opinion has been, that while motion beyond the normal range of flexion and lateral flexion are blocked by the chest and shoulders, no such restriction is placed upon extension (McNab 1973). This would suggest that the magnitude of neck extension would be related to injury.

Mertz and Patrick (1967&1971) proposed that the injuries arose from compression of dorsal structures and elongation of ventral structures. The rapid rebound from extension into flexion was also cited as a cause of muscular injury. In examining the role of muscle contraction in restricting neck motion, the authors found that although sufficient force could be established to brace the neck, the unprepared person could not react fast enough.

Burow (1975) tested cadaver vertebral column specimens that were sectioned at T_{10} in +X acceleration tests; however the specimens were mounted vertically. Spinal biomechanics in rear-end collision simulations were investigated. Impact velocities were between 18 and 25 km/h with mean acceleration pulses of 13 to 16 g's. The author found no relationship between the magnitude of cervical spine extension and resultant injury; either hyper-extension occurred without injury, or injury occurred with minimal extension. The author proposed that shear forces due to inertial segmental loading were responsible for injury; each inferior vertebra loaded the superior head-neck segment through soft and hard tissue structures. As a result of this indirect loading, highly localised loads could rupture the connective tissues between the vertebrae.

Burow postulated that as extension increased, compressive forces could be transferred along the dorsal structures of the vertebral column leading to spinous process fractures. When the orientation and strength of cervical spine ligaments are considered, the results of Burow's work are particularly meaningful.

Recently, a number of research groups have recommenced the examination of neck injury mechanisms in rear-end collisions, indicating that 'whiplash' is a continuing problem. McConnell et al. (1993) examined the kinematic responses of four volunteers in a series of low velocity collisions. Vehicle Δv's were between 3 and 9.3 km/h. Volunteers were instrumented with a triaxial accelerometer array secured to a biteblock and optical markers, each experiment was filmed. Following the experiments the subjects experienced mild transient neck pain. The authors observed that neck motion was within voluntary range, and that there was a consistent vertical acceleration of each volunteer's head. They

concluded that vertical forces, and not hyperextension, may have been associated with the resultant symptoms, indicating a compression-tension injury mechanism in 'whiplash'.

Geigl et al. (1994) conducted a similar series of experiments with a larger sample of volunteers (25 subjects in 37 tests). Cadaver tests were also conducted on an impact sled. Δv's were between 6 and 12 km/h for volunteers. Instrumentation was limited, however each test was filmed at high speed and optical markers were used. The authors observed that the head remained stationary until well into the impact, at that time it began to rotate backwards. During this phase of neck extension the trunk has begun to move in an anterior direction. The authors did not comment on vertical head motion.

Volunteer tests were undertaken by Matsushita et al. (1994). In these tests volunteers were subjected to low speed impacts and sequential radiographs were taken using cine-radiographic techniques. Sled Δv's were between 2.5 and 5.0 km/h.

In -X head/neck loadings some more developed criteria or statistical predictor models have been developed. Schmidt et al. (1992) assessed neck injury in 23 belt restrained cadavers in 0° vehicle impact simulations. Analysis of the head/neck kinematics through a logistic regression revealed a high correlation between head acceleration along the path and AIS injury severity.

Upon examining the available literature it is obvious that much more detailed information is required if neck injury is to be understood and minimised. Coordinated research is required in the fields of anatomy, biomechanics, ergonomics and accident research.

UNSW RESEARCH PROGRAMME.

UNSW has implemented a research programme designed to investigate some aspects of neck injury resulting from rear-end collisions. One component of this programme is an investigation of injury mechanisms, which is being undertaken in collaboration with the Discipline of Anatomy at the University of Newcastle. The research aims are:

- Investigate the kinematics/kinetics of the cervical spine during 'whiplash' loadings;
- Investigate resultant injury; and,
- Propose injury mechanisms, and develop injury and tolerance criteria.

Investigation of Injury Mechanisms.

To study the kinematics of neck motion and investigate resultant injury, a number of experiments are being conducted at UNSW with isolated human cadaver head neck specimens. Each test specimen will be subjected to a controlled inertial load and will then be examined anatomically and radiologically for resultant injury. The ethics of this research was considered and a code of practice developed in the US and Europe has been adopted (King et al 1993). Ethics Committee approval was sought successfully at UNSW and all legal requirements are being followed.

Test Matrix: A pilot study using two specimens is being undertaken to examine gross differences between specimen preparations. One specimen without musculature and one with musculature are being tested. Repeated tests will be performed at selected impact severities with each specimen. Gross kinematic data and minimal injury data will arise from this pilot study.

In Series A tests each specimen will have all musculature removed so as to examine the behaviour of the vertebrae uninfluenced by tension in the non-contractile muscle elements. The specimens will be examined for injury, and injury type and location will be compared to clinical data. The exposed vertebrae will facilitate accurate measurement of spinal motion.

In Series B tests representative muscle elements will be attached to specimen to examine their influence on the neck's kinematics and injury occurrence. The muscle elements will be attached to the exact origins and insertions, as determined during dissection. As the vertebrae will be exposed, optical marker visibility and placement will remain good. If clinically relevant pathology is replicated in Series A experiments, but the location of injury is incorrect, the addition of muscle forces may prove to influence this facet.

Depending on funding and specimen availability, Series 3 tests are planned with the optimal test specimen preparation and some form of head restraint.

Test Device: A test rig consisting of a mini-Hi G sled and impact pendulum has been designed and constructed at UNSW (figure 1). The test rig permits the sled to be accelerated under selected conditions, i.e. pulse shape, duration and acceleration magnitude. The sled is accelerated by the pendulum impacting a polymeric foam buffer attached to the sled, and is brought to rest over 1m. by a calliper brake.

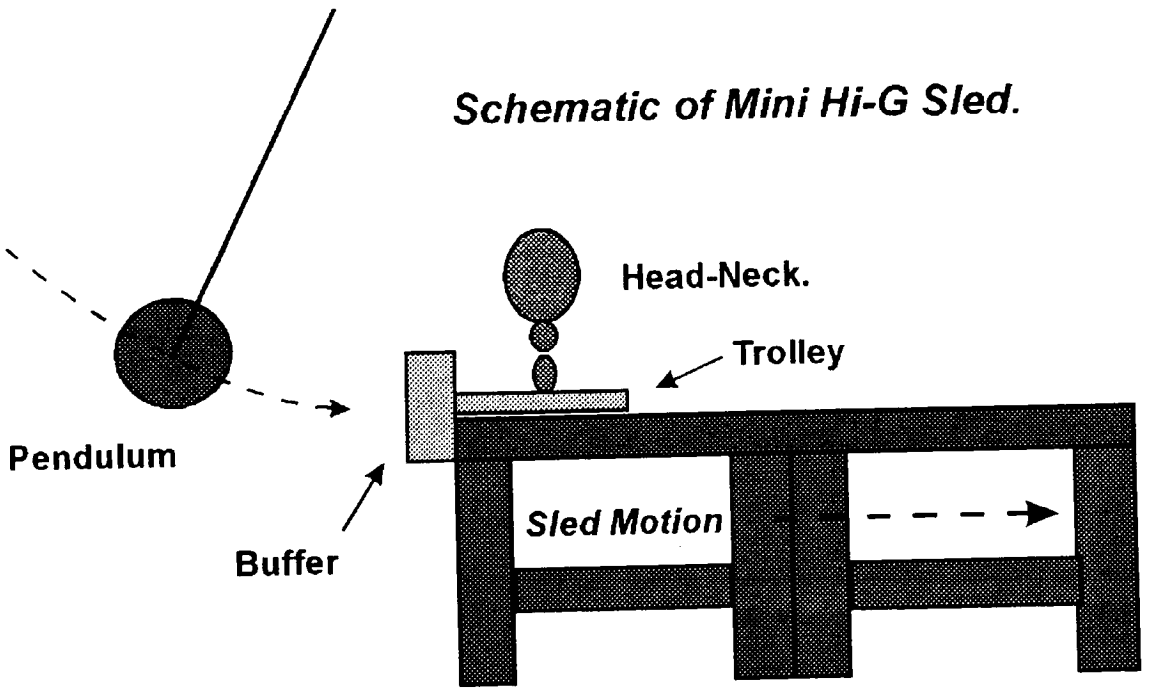
Instrumentation: The sled and head-neck specimens will be instrumented, and data will be acquired digitally at 10 kHz. A nine-accelerometer array will be mounted rigidly to the skull. The 3 axis 6 degrees of freedom motion of the head and neck loads will be calculated from the measured accelerations. From these data the forces and moments applied at the occipital condyle can be calculated, as well as the linear and angular accelerations of the head.

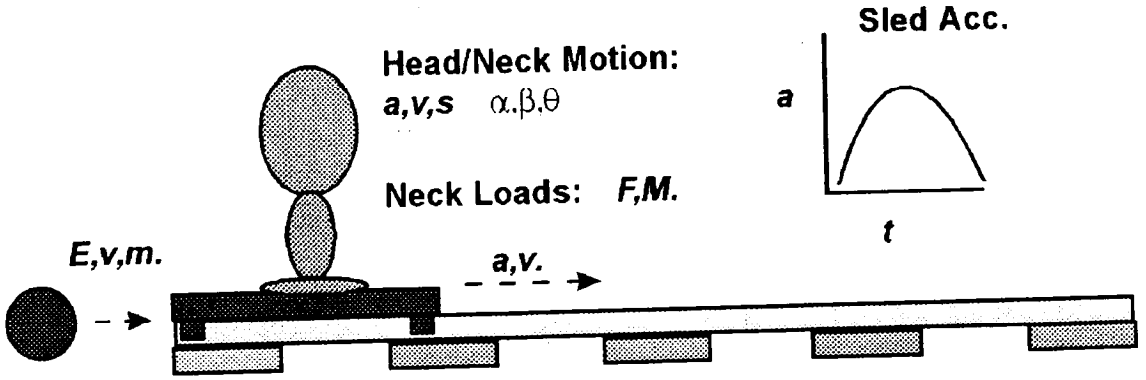
Optical markers and high speed cinematography will also be used to determine the displacements of selected vertebral segments. Metal pins will be mounted to the vertebrae and retroreflective markers will be attached to each pin.

The anatomical examination will be conducted at Newcastle University and each specimen will be carefully dissected to determine the geometry of the hard and soft tissues, and investigate injury. Radiological examination will also be performed. The research groups extensive database of injury descriptions will be employed to compare the experimental and clinical injury profiles.

Based on the results of these experiments the relationships between independent variables, e.g. neck moment, neck force or angular displacement, and the dependent variables, i.e. injury type, location and severity, will be examined. From this examination, injury and

Figure 1 (Top and Bottom) Sled and Measurement Systems





injury tolerance criteria will be developed. The results of these tests will then be used to assess seat and head restraint design, and to validate numerical models of the neck.

Sled tests were undertaken at the RTA Crashlab to measure the responses of an instrumented HYBRID III dummy in rear-end collision simulations. The behaviour of the seat back and head restraint were also examined. The input acceleration pulse for the initial tests has been modelled on the linear acceleration of the trunk (figure 2).

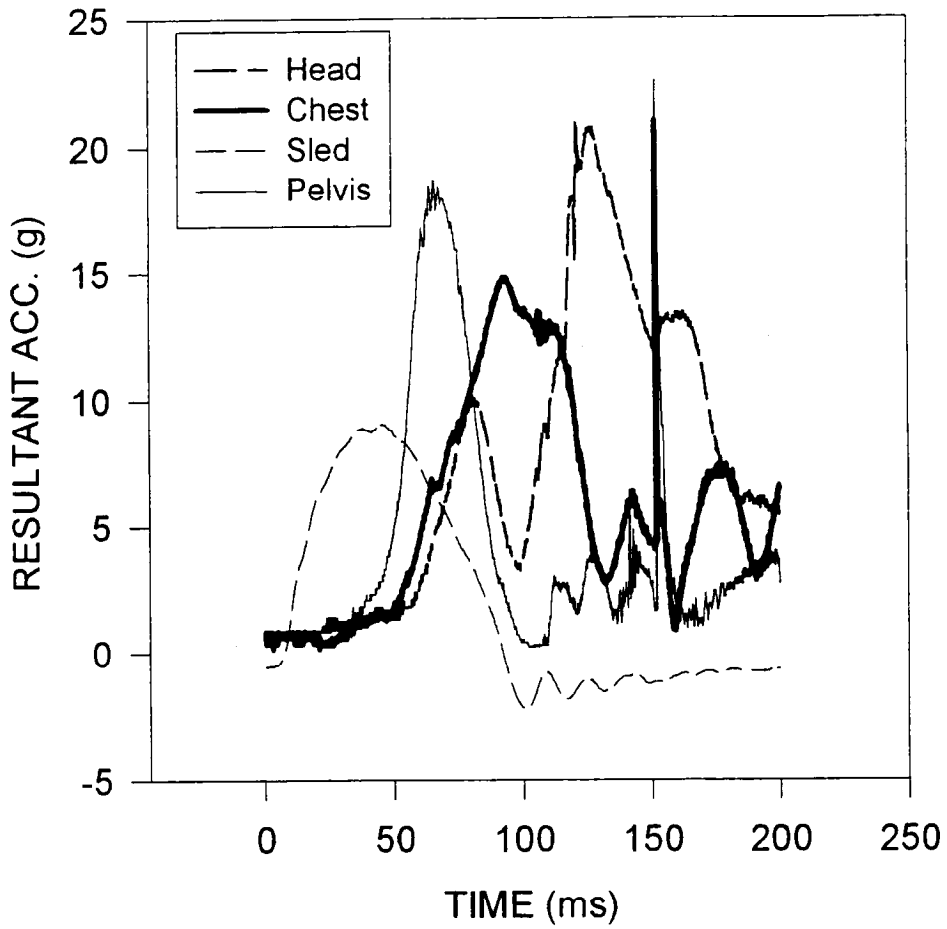


Figure 2: The Sequence of Body Acceleration Time-Histories from Crashlab sled tests with seated HYBRID III dummy in rear-end configuration.

Validation of 9-Accelerometer Array.

Preliminary experiments were undertaken using a HYBRID III head and neck to compare measured and calculated neck loads and head accelerations. Theses experiments were conducted at the RTA Crashlab, Sydney. The HYBRID III neck calibration test was modified by securing the 9 accelerometer mount to the top of the HYBRID III's head.

A common signal was supplied to both data acquisition systems to permit time alignment of the two data sets. Time histories analysed from the HYBRID III were: centre of gravity head acceleration, neck moment (My) and anterior-posterior neck force at the occiput. The data from the 9 head accelerometers was also analysed.

The MERTZ-3D program was used to analyse the accelerations from the 9 accelerometers and a single output file of: Head CG Linear accelerations (*Acgx*, *Acgy*, *Acgz* and *Acgr*(g)), Head Angular acceleration (αy(r/s^2)), Head angular velocity (αy(r/s)), Neck Moment (*My*(Nm)) and Neck Force (*Fx*(N)), was produced and analysed. In each case the 9 input acceleration files were again zeroed (to eliminate the centripetal Z axis acceleration) and filtered with 100 Hz. low pass digital filter. The maxima and shape of the time-histories were compared. Figures 3,4 and 5 present comparisons of resultant head centre of gravity accelerations, neck moments and forces. Table 1 presents a comparison of the acceleration, moment and force maxima between the two measurement methods. The results of these tests show that there is a good correlation (magnitude and shape) during the first 100 ms. of impact.

Table 1: Comparison of Measured and Calculated Head Acceleration, Neck Moment and Neck Force.

Experiment	Difference between Acc. maxima (g)		Difference between Fx maxima (N)		Difference between My maxima (Nm)	
	|acc|	%	|Fx|	%	|My|	%
95041	4	14	73	10	7	13
95042	3	10	67	9	6	11
95043	3	10	68	9	5	9
95044	5	15	66	9	6	10
95045	5	16	94	13	10	19
95046	4	13	102	14	8	15
Mean		13%		11%		13%

N.B: Percentage difference=(diff between maxima/measured maxima)%

SUMMARY.

- An investigation of neck kinematics and injury mechanisms in rear-end collisions is being undertaken in a collaborative project;
- The results of these tests can be compared with an extensive clinical database to validate selected injuries and their locations, e.g. facet joint injury;
- The accuracy of instrumentation and measurement methods has been shown to be valid and reliable.

Figure 3: Comparison of Measured and Calculated (9 acc. method) Head Acceleration.

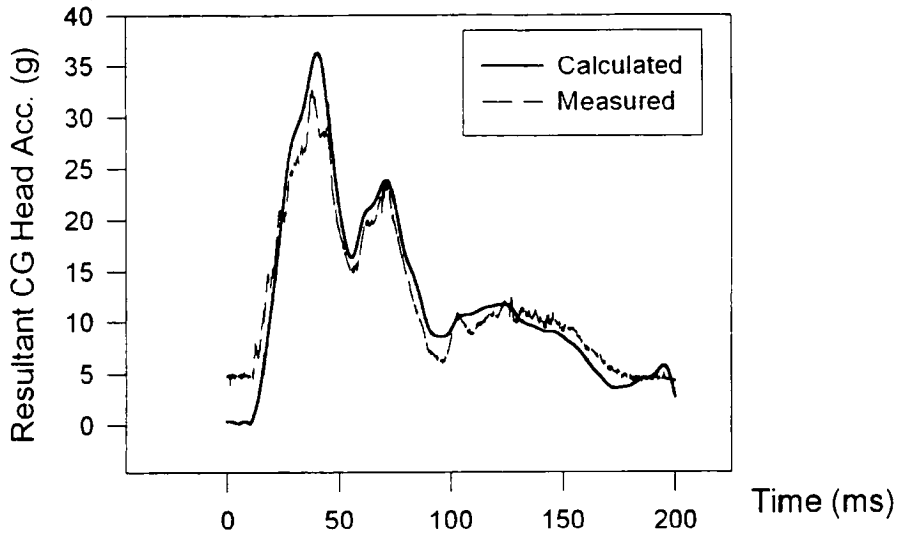


Figure 4: Comparison of Measured and Calculated (9-acc method) Neck Force (Fx)

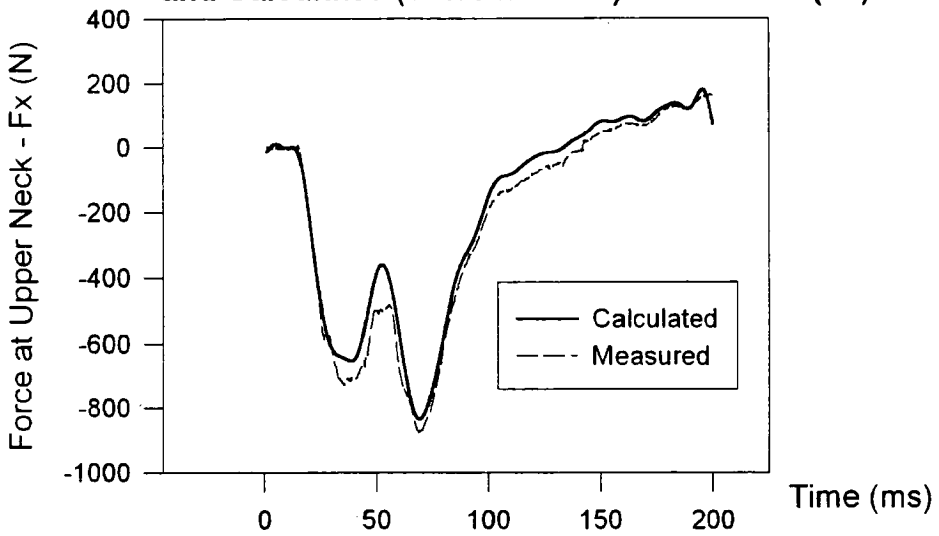
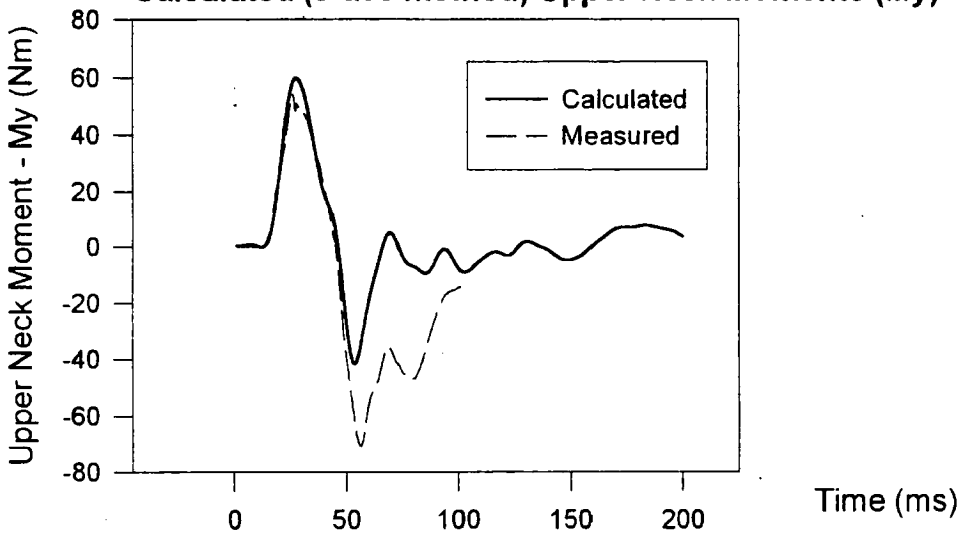


Figure 5: Comparison of Measured and Calculated (9-acc method) Upper Neck Moments (My)



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DISCUSSION

PAPER: **Methods For An Investigation Of "Whiplash" Injury**

PRESENTER: Dr. Andrew McIntosh, The University of New South Wales, Australia

QUESTION: George Aitken, Orthopaedic Surgeon, British Columbia, Canada which he states is presently the whiplash capital of the world.

ANSWER: Is that something to be proud of?

Q: No, that is not something to be proud of but it poses a major problem to us. We now have somewhere in the region of 998 per 100,000 populations. That's not drivers. It is premium holders. The actual figure of the people at risk is not known but is a very high number. The highest in the world at the present. Quebec, which has a totally no fault system, has somewhere in the region of 70 per 100,000. Australia has sized their incidence by changing lines and so on. So we have a real problem. The problem is: "why do some people hurt and why do others not? ." If you look at literature there is a lot of stuff on high velocity impact and there is not very much on the group in between that and low velocity impact. There is a fair amount of stuff on low velocity impact as well. The problem is: "what is the threshold?" The other problem is: "what happens to the guy in the bullet car?"

A: To what car?

Q: What happens to the guy in the bullet car, not the target car?

A: And one of the problems is if you are innocent, your perception of pain, which is what you are talking about basically, it is much higher than if you were guilty. This is something which is seen in clinical medicine, time and time again that people who are responsible for their own injury and where there is nobody else to turn around and sue or bring a case against or claim litigation, tend not to complain to the same degree as those who are not liable. So, I wish you luck in your endeavor but I'm not sure if you'll solve that question but I think you should look at the bullet vehicle as well as the target vehicle.

A: We're not trying to solve that problem. I think there are a number of things with reference to what your talking about, we're having to get more objective diagnosis for whiplash and this fits in with the program which is going on at the University of New Castle. We're collaborating with them. They have a spinal research unit. They're looking at whiplash and collaborating with them so in conjunction with them, we have to be able to address that particular topic as well. Not in looking at the psychological or legal atrogenesis of whiplash.

Q: Well, with all due respect though, that is just where it hits the pavement because society is based on enormous cost and has to have some reasonable way to say, "yes, this is legitimate pain" or "no, that's not legitimate pain." If you were to develop a scale, somewhat like Carson Sealyhams has for Ping golf clubs that you'd put the factor on the edge, height, distance of the

ears from the shoulder and so on and get a graph of that. That would be a great service. That would at least give us some reference point. If you do have something like that would serve the purpose very well.

A: Yes.

Q: There is just one thing I would like to say. Before I started this project, I was very suspicious of people claiming whiplash. Since I've been involved in the project, I'm less suspicious of people who claim whiplash because some of the anatomical studies I've seen which show significant trauma to some of the hard and soft tissues in the cervical spine which aren't picked up clinically with any type of medical imaging techniques and they're picked up on an autopsy. For that reason alone, when people claim whiplash, I'm probably less suspicious of what they are talking about. What I'm saying is that you can't really rely on the clinical tests either so there are two things that have to happen. The clinical tests have to improve to be able to help differentiate between people who are putting on pain for some secondary gain and for people have got a legitimate physical injury. Thanks.

Q: John Cavanaugh, Wayne State University
One of the leading investigators in whiplash and other spinal pain is Dr. Nicholas Bagdak.

A: Yes, that's who I collaborate with.

Q: Yes. I missed the first part of your talk but he attributes much of cervical spinal pain and whiplash pain to the fascia joints and claims good success in the nerve block to the fascia joints. What are your comments on this based on biomechanics?

A: Well, I think it would be too early to make any comments yet. Theoretically, I think it is very likely that with the orientation of the fascia joints in the cervical spine that either the articular cartilage in the fascia joint or the articular capsule is damaged due to either shape forces or excessive bending.

It doesn't seem as though that from the whiplash the amount of the motion and the range of motion is related to injury so it would seem more likely that due to the orientation that the lack of support structures in the cervical spine that could very well be a strong link between the two that we have to be able to investigate that.

Q: Hurley Robbins, TRW Vehicle Safety Systems
In addition to the spinal bones, there are the muscles which hold us erect. How do you anticipate dealing with the forces that can be in the musculature in its living state? Do you have any methodology set up for that?

A: We are going to actually assume that the person is totally relaxed and apart from having the head in a neutral position because that is a worst case. The best case is if the person knows that an accident is going to occur and they have their muscles fully activated.

Q: If your musculature is totally neutral, what happens when the head starts to move? Don't the muscles want to stay in the position that they're in?

A: I believe from some work which was done, I think by Mertz and Patrick, that they looked at reaction time. And other papers on reaction time don't allow for the person to respond. Although, the neo-muscular system to respond to that very small instrument of timing in which this type of accident occurs so that proprioceptive mechanisms won't really work really well. So, we are assuming the worst case which is to look at the articular structure and not the muscular structure. I think, maybe, using modeling methods, it might be possible then to examine the effect of the muscles later.

Q: Guy Nusholtz, Chrysler Corporation

Just sort of three comments with regard to your request for possible areas to look at. One would be a brain flap. The other is the effect of impedance at the terminal and the last one would is related to measuring the load cell loads at the point where you've looked a spine into.

One of the things that happens with cadavers is that if they sit for any length of time or they sit in a cooler, the brain can settle. It can move away from the skull. And then when you impact it, when you move it, it moves differentially with respect to the skull and then when you are measuring non-accelerations on the skull, you're not really getting a force because you are basically estimating a mass.

So one way to check for that is just to run an x-ray through the head before you impact it, to see if there is any air space. That's a check that's been used in the past.

The other is, I think you said you were locking in a T3, T4 area.

A: Yes. And T5 and T6 will be locked.

Q: OK. The impedance where the cervical spine goes into the thoracic spine. How that response is going to affect the motion of the rest of it so you might consider what the effect is of your preparation by perhaps doing one, where you lack in a T2 and another where you lack it in a T4 and a check to see what that effect is going to have.

You might also want to look at the triaxial accelerations of the uniaxial acceleration at T12 because its rotation will also be important, as well as its linear motion.

Q: Thanks.

Q: Srini Sundararajan, Ford Motor Company

Do you plan to take into account the shear effects?

A: We're happy to be able to calculate what the shear forces are at the occipital condyle and then maybe we can estimate, calculate, what the shear forces between some of the vertebrae where we have cinematic markers so we can help with displacement.

Q: OK.

A: But I suspect that the way that we'll do that is coincident with this project is, we'll be doing some numerical modeling and I believe that if we use the data from this as an input into, say a small scale finite element model to which I send vertebral segments. We can then maybe examine more closely what this shear forces of strain stresses are at the set joints in the disk.

Q: Thank you.

Q: Malcolm Robbins, Robbins and Associates

I actually work for myself. I actually am an accident reconstructionist and I've given a paper on whiplash. I wondered, with all the research you are doing, have you ever consulted somebody that's actually done a study of the effects of a whiplash in a vehicle that actually doesn't show any appreciable sign of damage yet. The person involved in the accident actually sustained a whiplash injury.

A: What do you mean a car hasn't sustained any damage or the person hasn't? The actual vehicle shows little or no appreciable damage at all.

Q: Well that's got something to do with the vehicle dynamics but obviously the person was exposed to some sort of impulse and I mean I'm not really looking at the interface between the two cars. I'm looking at us finding an interface between the seat and the person, either due to the stiffness of the car or its elasticity or something like that. There is no damage. I mean, if you had two cars in compatible mass or size then I'd assume that you had that particular type of problem.

A: Well, actually, if you think about it, if the car isn't going to give at all and it is a complete solid body, when the bullet vehicle hits the receiving vehicle, then the "g" force is totally transferred theoretically an instantaneous incidence. Therefore, the "g" force the occupants are going to receive, it's going to be literally instantaneous too.

Q: All except for the six deformable, the six not rigid so it's going to impart a different acceleration impulse to the track than a car will. Because interface between the human and the vehicle is the seat, not the back of the car.

A: Well, I'd like to answer that. First of all, if you've ever seen any high speed photography, you'll actually see that the head actually stays in its place and the lower trunk moves forward and the reason being is that the surface area off the seat is so high that it doesn't give at all, or very little.

The head is actually remaining behind and the trunk is propelled forward and that is the very mechanism of a whiplash effect. So the softness of a seat has little to do with the cushioning effect of a whiplash effect and if you see any photographs, you'll actually see that.

Q: But we did some sled tests with a standard seat in a rear end collision and I can assure you that the seat collapsed severely in a very low severity rear end collision simulation so I don't know whether we're talking across purposes or not.

A: I think we are and if you would like to consult me later, I'll give you some suitable witnesses.

Q: Well, we're just looking at the interface between the seat and the person that is what this was about and what the pendulum is providing is that impulse that is provided to the set of the center of gravity of the thorax. We can make that a higher severity loss, a very long duration, shorter duration. So we're not really looking at the vehicle dynamics which is what I suspect you are talking about.

A: Well, I thought that was the purpose of your research.

Q: Well, the purpose of the research isn't to look at the vehicle dynamics.

A: Oh, I'm sorry. I was mistaken.

Q: Thank you.

Q: N. Yoganandan, Medical College of Wisconsin

This is obviously a very important topic. I have one question for you. Whiplash is a kind of a longitudinal phenomenon. You just don't develop it right away. Some people do develop it right away. Some people don't. Do you have any plans of including this longitudinal phenomenon either in your modeling or in your experimental work and try to comment on some kind of neuro-muscular or neuro-vascular kind of tissues that may be involved in causing the whiplash pain?

A: We hadn't, but it is a very interesting point. I think the group that we're collaborating with at New Castle University has probably the opportunity of looking at it clinically but I don't think we have an opportunity of looking at it experimentally and I really hadn't thought about extrapolating that for some sort of biomechanical neomuscular devices like that, I hadn't thought about it. I mean, it could be possible but we hadn't thought about it.

Q: Michael Barrett, JFK Engineering

I'm from here in California which is the second whiplash capital of the world. A couple concerns about your testing. You're attaching the test specimen rigidly to the sled at a T5 level. Especially up at the higher,

A: T5 will be fixed and T4 will be exposed and so we'll have the upper thoracic spine has some mobility and so we'd like to include that in the model.

Q: OK. I'll make this brief. On your higher impact severity is up to, I believe you said six meters per second, you are going to get appreciable seat back deformation in most production seats.

There is obviously a wide variance in the strength of production seats so you're going to get appreciable deformation which is going to change the torso angle. I am wondering whether rigidly mounting even down at T4 to the sled, if that isn't a worse case of severity to the cervical spine at that severity. It strikes me that it may be worst case. It'll be imparting a much more serious act than an occupant would actually experience in a seat that you have seat back deformation.

A: I think the answer to that is that there is obviously a vertical component of displacement and acceleration of the trunk in a collapsing seat. We can't do that in a very controlled way in these type of tests. What we're trying to do is have a very controlled experiment in which we can account for most of the independent parameters in the test, and do it in a controlled way so we can really assess the effect of those on the independent variables. So including another variable like that will make it more difficult to establish any sort of relationship. But I agree with what you are saying.

Q: I agree. It would make it very difficult to control.

And the second thing is, you are going even at the higher severity of six meters per second, you're still only seeing an 80-millisecond pulse for chest acceleration because it strikes me that with a deforming seat back that may be a little bit short of a pulse which is again, a worst case. I haven't your sled test data but it seems to be a little bit short compared to some of the stuff I've seen.

A: I think that with that speed, we'd probably have a shorter, I'd say. I think that would be right. We're still looking at other materials that we can use but it seems that to get a longer duration impact of say 100 milliseconds, is very difficult with the materials that I've looked at so far. Looking at different preliminary findings. To get a good reproducible pulse, we want to rely on the type of result that we get; that limits the type of material that we can use.

Q: Thanks very much.