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PEDESTRIAN TRAUMA, COMPARISON OF REAL WORLD AND CADAVER INJURIES

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INTRODUCTION

The purpose of this paper is to further demonstrate that human cadavers are appropriate surrogates for predicting and evaluating 'real world' injury causation to pedestrian accident victims and to discuss two significant aspects of this study. They are:

1. The sensitivity of the subject's geometric attitude at the time of impact on the kinematics of the person (subject) and the injuries observed.

2. The laboratory techniques used in the preparation, exposure, autopsy and dissection of the cadavers and the victim.

During the course of laboratory experiments using human cadavers as pedestrian surrogates, it came to the attention of the authors that the gross injuries to some of the cadaveric subjects closely mimicked those observed on a real world pedestrian victim who had been struck by a similarly shaped vehicle at a speed estimated to be close to that of the sled test vehicle (body buck).

The accident victim was a 75 year old female, approximately 100 pounds in weight and sixty inches in height. She was struck on the right side by a 1983 Plymouth Horizon and sustained fatal injuries. Based on information supplied in the police accident report the authors estimate the impact velocity to be between 20 and 25 mph.

The victim had submitted the necessary donation forms to the willed body program at the State University of New York at Buffalo (SUNYAB). When the body was delivered to the Department of Anatomical Sciences it was determined that the injuries were too extensive for successful use of the body for teaching purposes and that the proper use of the subject would be for research purposes. This decision, to perform radiologic, gross autopsy and detailed dissection studies on the pedestrian fatality, presented the research team with the unique opportunity to make comparisons of laboratory versus real-world injury studies. These studies, comparable to those that were being performed on cadaver subjects exposed to laboratory impacts, allowed the comparison of the injuries of an actual pedestrian accident victim with those of the laboratory pedestrian subjects.

This program consisted of the evaluation of the injuries resulting from three controlled laboratory experiments using human cadavers as pedestrian surrogates and one 'real world' accident victim. The injuries discussed will be limited to those observed in the upper torso, the head, and the neck of each surrogate and the accident victim.

PROCEDURES

The laboratory experiments using human cadavers were performed on the Arvin/Calspan Advanced Technology Center (ATC) 12 inch HYGE sled facility using a body buck fabricated from the front end (bumper to windshield header) of a 1984 Mazda 626. All sled tests were performed at a nominal striking velocity of 25 mph with a deceleration at impact of 0.75 Gx.

There was no attempt at re-pressurization of the arterial system of the cadavers during these reported experiments. This lack of pressurization precludes some trauma evaluation in the upper torso and the brain. Linear acceleration measurements were recorded from both externally mounted and surgically implanted accelerometers on the cadaveric subjects but as of the writing of this paper these data are not available to the authors through the NHTSA Biomechanics Data Base.

Cadavers were supplied for this research by the SUNYAB Department of Anatomical Sciences. All cadavers had been previously donated to the University's willed body program. After the experiments the subjects were returned to the SUNYAB for disposition according to the willing documents. Strict adherence to NHTSA Order 700-4 was observed in all instances. For identification purposes human cadavers are referred to as Calman XX. Calman is a generic name used by Calspan to designate a cadaver subject. The number is a serial number which provides a means of reference while maintaining the anonymity of the donor. The cadavers used in this study are referred to as Calman 43, 44 and 45.

Pedestrian subjects were positioned to simulate a walking stance with the struck leg placed at the midline of the bumper. All impacts were performed on the left side of the subject. The struck arm was secured behind the subject's back to preclude premature contact with the hood and the subject was loosely tethered to the vehicle to preclude secondary contact with the ground. A quick release mechanism (explosive cable cutter) attached to the body harness supporting the subject was electronically actuated at a programmed time in the sled start-up sequence to allow the subject to be 'free standing' at the time of impact with between fifty and eighty percent of the body weight supported by the struck leg.

Whole body x-rays were exposed and examined by a radiologist before and after the experiment. An autopsy examination was performed by a forensic pathologist and the lower extremities and head were dissected by a neuroanatomist. The results of these examinations were sent to the Department of Orthopedics of the University of Rochester for evaluation of potential temporary and permanent impairment.

ANTHROPOMETRY AND KINEMATICS

The cadavers used in this study included a 48 year old male, a 72 year old male and a 42 year old female. Selected anthropometric data of these three subjects and the accident victim are presented in Table 1.

TABLE 1 - ANTHROPOMETRY

SUBJECT	SEX	AGE	HEIGHT(in.)	WEIGHT (lb.)
Calman 43	M	48	74.5	187
Calman 44	M	72	68	175
Calman 45	F	42	63.5	90
Victim	F	75	60	100

The initial stance and kinematics of the cadaver subjects were analyzed from pre-test still photographs and high-speed films of the impact. A summary of these is presented below:

CALMAN 43

INITIAL STANCE: The subject's hips were aligned perpendicular to the vehicle front (parallel to the velocity vector). The right thigh was closely aligned but perhaps slightly behind the left (within an inch). The shoulders were slightly canted toward the vehicle at an angle of less than ten degrees.

KINEMATICS: At impact the hips rotated immediately in a clockwise direction (referenced to the mid-sagittal plane) while the upper torso remained in it's original orientation to the velocity vector until the left shoulder and rib cage contacted the hood. The angular momentum of the hips and lower extremities then caused clockwise rotation of the upper torso forcing the subject to roll onto his back. The subject's legs extended up over his head and the roof of the vehicle causing hyperflexion of the neck.

CALMAN 44

INITIAL STANCE: The hips of the subject were canted slightly toward the vehicle (approximately 10 degrees). The right thigh appeared to be forward of the left thigh (within an inch) although the right knee was aligned or slightly behind the left knee (less than an inch).

KINEMATICS: At impact the body rotated counter-clockwise and the subject landed frontally on the hood. His head contacted the windshield and cowling. Once the torso was in contact with the hood the lower extremities pivoted over the head and above the roof of the vehicle causing hyperextension of the neck.

CALMAN 45

INITIAL STANCE: This subject's hips were perpendicular to the vehicle front (parallel to the velocity vector) and the shoulders were canted slightly more than 10 degrees toward the vehicle. The upper torso was somewhat flexed. The right thigh was within an inch in front of the left thigh.

KINEMATICS: At impact the body rotated counter-clockwise and the subject landed frontally on the hood. The head contacted the cowling. After full torso contact with the hood the lower extremities pivoted over the subject's head and the roof of the vehicle. The subject then rotated to the right side causing lateral flexion of the neck. This late rotation was artifactual to the tethering device used to contain the subject on the vehicle.

INJURIES

The upper torso, head and neck injuries observed on the three cadaver subjects and the accident victim are summarized below in Table 2.

TABLE 2 - UPPER TORSO, HEAD AND NECK INJURIES

SUBJECT	INJURIES
Calman 43	Multiple rib fractures: LR1(1), LR2 through LR6(2), RR2(1),dislocation of acromio-clavicular joint, left scapula fracture.
Calman 44	Left zygomatic-facial and temporal nerves severed, separation between C4 body and disc above C5 body, left shoulder contusion.
Calman 45	Fractures of RR1 and LR2, displaced fracture of zygomatic arch, zygomatic bone displaced laterally in orbit and periorbital fascia lacerated.
Victim	Multiple rib fractures: RR1(1), RR2 through RR8(2), RR9(1),LR1 through LR2(1), LR3(2), LR4 through LR5(1), right lung contusion, sternum fracture, subcapital fracture of right humerus, communuted fracture of right ulna.
	Extensive subdural hemorrahage, bilateral superior brain contusions (both hemispheres - mid to posterior), deep scalp contusion on left superior scalp.

DISCUSSION

Human cadavers are very difficult to position upright in a simulated walking stance. Although care was taken to stand the three cadavers in the same attitudes, the slight differences noted in their initial stances appear to have had a significant effect on their resulting kinematics. For example, Calman 43 and 45 were both aligned with their hips parallel to the velocity vector and their shoulders canted toward the front of the vehicle. Calman 43's right thigh may have been slightly behind the left (within an inch) and his shoulders were canted less than ten degrees toward the oncoming vehicle while Calman 45's right thigh was within an inch in front of the left thigh and her shoulders were canted approximately ten degrees toward the vehicle. Calman 43 rotated in a clockwise direction (referenced to the mid-sagittal plane) and Calman 45 rotated counter-clockwise. Although these subjects (Calman 43 and 45) were dissimilar in weight and stature, which contributes to their kinematics, it is believed that the small differences in alignment had more effect on the resulting motions than the anthropometry differences. The kinematics observed during the Calman 44 test were more similar to Calman 45's. His right thigh was also within an inch in front of his left thigh while his hips were canted about ten degrees toward the vehicle. This subject also rotated counter-clockwise (toward the vehicle).

The female accident victim sustained upper torso injuries comparable to those observed during the autopsies and dissections of Calman 43 (i.e. multiple rib fractures on the impacted side, fracture of the first rib on the unstruck side and upper extremity trauma on the struck side). It is apparent that these injuries occurred from contact with the vehicle hood. The accident victim also sustained severe brain injuries which may have occurred at the time of impact with the vehicle or from secondary impact (with the ground). Since the arterial systems of the cadavers were not pressurized (including attempts at tissue staining), subdural hemorrhages and brain contusions were less likely to be, and in fact could not be determined from brain dissections.

Based upon an analysis of accident scene data (skid marks, impact point, rest point, etc.) and the similarity of the upper extremity trauma between the accident victim and Calman 43, we believe that she was struck on the right side at a speed of between 20 and 25 mph by a vehicle with a reasonably low front profile. Since there were no neck injuries, she probably rotated onto her back (induced flexion) or remained on her right side (induced lateral flexion) while she was on the hood. It cannot be determined whether her head contacted the cowling or windshield.

Her head may have contacted the cowling although she was quite short. Her Wrap Around Distance (WAD) and lack of right side or frontal head injuries would indicate that this contact was not likely. This statement is made even though head contact with the cowling was observed during the Calman 45 sled test. This subject was also of slight stature with a WAD less than the distance from the ground to the cowling. However, Calman 45 exhibited left side (struck side) and frontal head and facial trauma while the pedestrian victim displayed only left side (unstruck side) head and facial trauma. Since the victim was struck on the right side, the head and facial injuries must have been caused by contact with the ground.

CONCLUSIONS

The following conclusions have been reached based on this data:

(1) Human cadavers are good surrogates for experimental studies of pedestrian accident trauma.

(2) In addition to looking at gross skeletal and organ injuries, cadaver subjects should be pressurized during experiments to help identify trauma to the heart, lungs, arterial system and brain.

(3) The kinematics of pedestrian human subjects are strongly dependent on the stance of the subject at time of impact.

(4) It is extremely difficult to repeat pedestrian experiments using human cadavers due to the variability in human subjects and the difficulties experienced in positioning these subjects in a realistic stance.

(5) The upper torso, head and neck injuries observed from pedestrian impact experiments are strongly dependent on the overall gross kinematics of the subject.

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DISCUSSION

PAPER: Pedestrian Trauma, Comparison of Real World and Cadaver Injuries.

SPEAKER: B.J. Kelleher

Q: Arnold Johnson, NHTSA
What sort of damage occurred to the vehicle in the actual accident compared to those in the sled test?

A: We never did get to see the vehicle, and the accident report did not have, that is the accident report that they gave us, they just gave us the pedestrian information, did not have any estimated damage to the vehicle so we were not able to find that out.

Q: Carley Ward, Biodynamics Engineering, Inc.
Could you summarize the neck injuries again and how they related to the kinematics of the impacts?

A: The only neck injuries we say in these four were C5, C6 dislocation and the cadaver that hit frontal and then went up on his neck and went into hyperextension. What I did mention is that we had seen that in an earlier study, where we did eight cadavers and I think four out of the eight rolled that way and we saw the same type of thing, one thing I did not mention and I meant to mention in the summary was, we can't tell whether there are any brain contusions or any other thoracic organ contusions from these pedestrian subjects because they haven't been pressurized and perhaps in the future it might be considered that the arterial system should be pressurized in the trunk and in the head and that the lungs should be pressurized.

Q: Claude Tarriere, Peugeot-Renault
I have understood then, when you have observed neck dislocation the impact was against this part of the vehicle between the bonnet and the windshield that is to say that in a stiff area of the car, and maybe this in part again, this stiff part of the car could explain the dislocation of the neck. Isn't that the first sequences and the head part was against the windshield no?

A: Yes, it was against the windshield.

Q: So if the goal that you have is to explain the scatter between different objects, of course you have to take account the difference between impact, impact too soon, stiffness of this part and also characteristics of the subject. So my next question is, do you have the bone characterization for the different subjects to explain differences between inner ability?

A: I don't have the bone information, we did PCA analysis and Calspan has done, I believe, the rib breaking the Granick and Stein. I don't have that information, maybe Calspan would be happy to give it to you. The vehicle, that we had in the front of this vehicle, under the bonnet, was we had a simulated air cleaner which was the only hard spot under the hood and on that air cleaner we had it chalked and there was about an inch and a half gap between the inside of the hood and the chalked area. This chalked hard area was a simulated air cleaner and there was no contact or very very little contact in that area by the head so I don't think it was a function of the head coming down so hard on the hard part of the bonnet as it was the fact that the whole body rotated around and he went into such hypextension.

Q: John Williams, Intera Technology
Have you any data on if there's any difference between a live body and a cadaver as how much, or is there much affect on the muscles or are the forces doing impact so great that the muscle wouldn't make any difference?

A: We can't find any volunteers for this program.

Q: John States, University of Rochester
I want to ask C. Tarrier a question. Claude did you believe that the cervical vertebra failed or was it the vertebra displacement backwards above the injury site relative to the vertebra below? What we found was that the anterior longitudinal ligament of the spine and the annulus were torn along with some of the muscle in the anterior aspect of the neck. This is what indicated to me and to us that the neck was hyperextended. It opened up in front and then it just closed up again so that the x-rays showed very little evidence of injury. The injury is almost undetectible on the x-ray but it was quiet obvious at the disection.