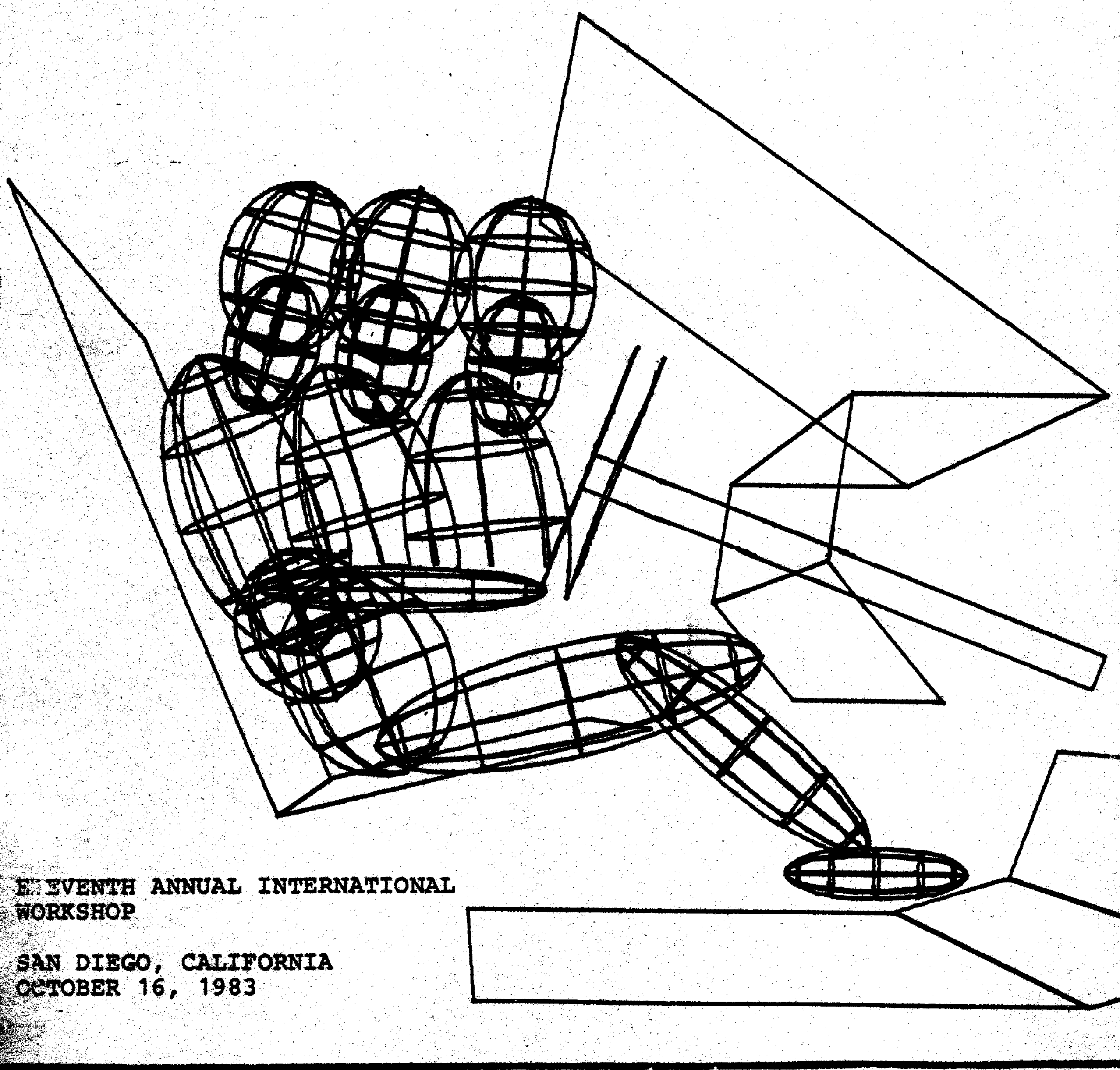
HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH



ELEVENTH ANNUAL INTERNATIONAL WORKSHOP

SAN DIEGO, CALIFORNIA
OCTOBER 16, 1983

INTERNATIONAL WORKSHOP ON HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH

Eleventh Annual Meeting
San Diego, California
October 16, 1983

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INTRODUCTORY REMARKS

The Eleventh Annual Meeting of the Workshop on Human Subjects for Biomechanical Research was held on October 16, 1983, in San Diego, California. Attendance was in excess of sixty for the ten scheduled technical papers and panel discussion.

For those of you who are not acquainted with the purpose of these workshops; the aim is to provide the research community with a forum for the presentation of new and preliminary results before they can be published in a journal article or an extended abstract. This mechanism provides workers in the field access to new data and techniques before they are formally published. The workshop is not intended to supplement or in any way replace the function of the Stapp Car Crash Conference. It is held in conjunction with the Stapp Conference to facilitate attendance at both meetings.

In accordance with the policy of our workshop committee, we have kept the meeting format informal. In addition to scheduled papers, presentations are accepted up until the day of the meeting if time allows. Presentations are printed each year in the form of proceedings which are sent to all interested researchers. However, these proceedings are not formal publications and should not be referenced.

We would like to extend our thanks to the Stapp Conference Advisory Committee for their continuing support of this activity, the SAE for administrative services and refreshments, and to Mr. David Foust who has served as secretary and who has provided for our printed proceedings each year a summary of the papers with associated questions or comments from the floor.

John Melvin Richard Morgan

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SYNOPSIS OF WORKSHOP

The Eleventh Annual International Workshop on Human Subjects for Biomechanical Research was held at the San Diego Hilton, San Diego, California, immediately preceeding the 27th Stapp Car Crash Conference. Dr. John W. Melvin of the University of Michigan Transportation Research Institute (UMTRI) chaired the workshop. More than fifty (50) persons attended.

Dr. Melvin discussed the nature of the workshop, noting that it is intended to provide an informal atmosphere for the discussion of recent research findings. Workshop participants and recipients of these proceedings are reminded that the "papers" presented in this informal setting are not "publications" and should not be cited as such in any reference bibliography.

Dr. Melvin announced that there would be no report from the International Standards Organization Technical Committee 108/Subcommittee 4/Working Group 4 on Human Impact Testing and Evaluation. It has not been possible for the Working Group to meet since the October 1982 workshop.

TECHNICAL SESSIONS

1. Interactive Pre-and Post-Processor in the CVS Model
   M. Schlumf and F.H. Walz, Institute of Forensic Medicine, Zurich.

Mr. Schlumf presented the paper which compares the kinematics of several types of pedestrian surrogates under similar test conditions. Cadavers, Part 572 and OGLE MIRA anthropomorphic dummies and the Calspan 3D Crash Victim Simulation (CVS) were used as surrogates.

A sophisticated marker/camera system is used to document the location of targets on the cadavers and dummies. Using a semi-automatic film analyzer, up to 300 frames from each of four high-speed films can be analyzed for the position of up to 30 high-contrast markers on the head. The lab does not attempt a second-order analysis of displacement data to calculate HIC, rather they measure linear acceleration directly. However, in post-test comparisons of velocity calculated both by integrating acceleration and differentiating displacement, an excellent match was achieved. Also, body kinematics measured from a film were compared with a Calspan CVS simulation, and a good match was achieved.

Mr. Schlumf presented test results from identical 25 mph tests in which a modified Volkswagen Rabbit front end impacted a cadaver and the NHTSA

Part 572 and OGLE MIRA ATD's. The OGLE MIRA dummy rotated fastest, with the head striking closer to the front of the hood; the cadaver head struck closer to the windshield base; and the stiff hip and shoulder of the Part 572 dummy prevented head contact to the hood.

The Calspan CVS model produces good results, but selecting links and specifying initial conditions is a very complex process. To facilitate data input and reduce mistakes, the Institute has developed a pre-processor program. Using this pre-processor and the Calspan CVS, a series of parametric studies was conducted to illustrate the influence of initial leg position on head impact location. They also studied effects of various impact speeds, and of different bumper shapes and hood leading edge heights at a constant impact velocity of 45 kph.

Based on this work, the researchers have concluded that the Calspan CVS is an efficient and reliable tool to simulate pedestrian impacts.

In the question period, Mr. Schlumf was asked about the source of stiffness properties used for the legs and the vehicle. He replied that he measured the vehicle front end and Calspan had measured the dummies. The questioner commented that access to the input data would be valuable in evaluating the comparisons presented.

2. Recent Developments in Biomechanical Modeling
M. Chi, Chi Associates

Dr. Chi briefly reviewed recent proprietary work of Chi Associates in five areas of biomechanical modeling:

a. Calspan CVS modeling of pedestrian in equilibrium. He has been able to establish a static equilibrium, then modify the model for dynamic equilibrium. Dr. Chi noted it is more difficult to simulate a cadaver than the NHTSA Part 572 ATD. He is attempting to model deformable body segments for the ATD using CVS.

b. Compressible steering column modeling in 3-D. He has developed a steering wheel model using a circular disk rather than a true rim because it is not possible to specify the variable stiffness necessary for a true rim. However, this model does simulate contact through the wheel disk rather than directly through the steering column. He is able to simulate both wheel deformation and column compression. Preliminary results indicate generally correct simulations, although the model is not yet verified.

c. Modeling of Wright-Patterson harness restraint system. Dr. Chi has been able to include many harness/occupant contact points in the model. However, modeling of belt webbing spooling from the retractor (a "tough problem") has not yet been achieved.

d. CVS modeling of seated passenger. Using the Wright-Patterson harness, a Volvo interior, and default values for segment length, Dr. Chi has simulated eight tests conducted by the University of Heidelberg. All tests were for identical seating position and vehicle deceleration, the occupants were varied among adult males and females, and children. The CVS post-processor was modified during this project, and a restraint system image was added to the graphics locally, outside the model. This improves efficiency of the CVS model.

e. Pedestrian simulations. Initial runs with the HSRI 3-D and Calspan CVS models produced trajectories which were too high. A better simulation was achieved after some modifications to the model, and good displacement comparisons were achieved with laboratory tests.

Dr. Chi summarized by noting that he has achieved greater efficiency with the CVS model by using local data pre-processing for input and local graphics for output. He has also made modifications which enhance the capability of CVS.

3. <u>NHTSA Data Base Filtering and Sampling Rates</u>
J. Marcus, NHTSA

Filtering of biomechanical test data has been standardized by NHTSA, and the data from these tests are being used to develop new dummies and determine "injury criteria" from dummy test results. To investigate whether data were being distorted, a thoracic model was run with and without filtering. "Injury criteria" were established for assumed levels of peak force, chest compression and acceleration at sternum or spine. Multiple runs were conducted at five different velocities of impact, with varying digital filters. There were changes in absolute values of peak force and acceleration but no changes in the ratio of lowest speed value to highest speed value. Chest compression occurs at too low a frequency to be affected by filtering techniques.

When he constructed a normalized frequency curve from unfiltered test data, Mr. Marcus found no significant data at or above NHTSA's most common filtering level. From the results, he concluded that current data processing does not distort the data, and the data may be used to develop test dummies and injury criteria.

Mr. Marcus received several questions. One researcher disagreed that these data may be used to develop injury criteria values. He noted that a two-mass model cannot be representative of injury, since the most serious problem is knowing what is relevant data. He cited the example of missing a high-acceleration spike which could cause serious injury (for example, a rib fracture which perforates the pericardium). Mr. Marcus replied that, while it is true certain data may be missed by filtering, filtering is appropriate for the uses to which he puts the data. Another researcher continued the point, emphasizing that low frequency represents gross motion, while high frequencies (which may be filtered out) may well represent the injury-causing phenomena.

Mr. Marcus acknowledged that he could not identify such relationships between high-frequency occurrences and injury because such occurrences are too instantaneous. In answer to a final question, Mr. Marcus explained that unfiltered data are transmitted to NHTSA, and that NHTSA processes the data in-house. Currently, only chest data are being filtered.

4. Advanced Dummy Instrumentation and Standards for 9 Accelerometer Array
G. Plank, DOT Transportation Systems Center

Mr. Plank reported on two aspects of the Advanced Crash Test Instrumentation and Acceleration System Studies currently being sponsored by NHTSA in support of advanced dummy development.

Initially, NHTSA anticipated processing test data on-board the dummy. A lack of space for signal conditioning equipment prevented that approach, so the current plan is to have the sensors with amplifiers and A-D conversion on the dummy and the memory and power supply in the vehicle. Alternatively, they are also considering A-D conversion and filtering in the off-dummy on-vehicle package. Automatic pre- and post-test calibration of each sensor is planned.

TSC is charged with recommending the calibration system for the next generation of test dummies, so they are currently conducting a Calibration Technology Assessment task. To date, basic calibration parameters have been established of: frequency, 1000 Hz; linear acceleration, 350 g, and angular acceleration 10,000 rad/sec^2. Off-dummy calibration will be by shaker table for linear acceleration and by available devices for angular acceleration. Since a motor-encoder set would be needed for angular accelerometers, TSC is recommending that linear accelerometers in fixed arrays be used in the new dummy (same concept as Part 572).

TSC is also developing standardization recommendations for the nine-accelerometer arrays which will be used so angular acceleration may be calculated from linear accelerometer output. Specifications are being developed for transducer selection, array configuration and block machining. TSC will then have a prototype constructed to their specifications.

Nine-accelerometer configurations of 3-2-2-2 and 3-3-3 are being examined. The effect of rapidly-multiplying errors in angular acceleration has been studied (see accompanying paper in these proceedings). A contrast of sampling rates (2000 Hz vs 8000 Hz vs 1 megahertz) showed that there is virtually no difference in output between the higher frequency sampling rates, but the calculations "blow up" rapidly at 2000 Hz rates. Therefore 8000 Hz sampling rates are recommended.

Comparing pulse durations for the 3-2-2-2 and 3-3-3 arrays showed minimal error differences for a 10 msec pulse. The integration process leads to a large error buildup in the 3-2-2-2 array for a 100 msec pulse. TSC noted that, for 20-30 msec pulses, the 3-3-3 array should be appropriate.

In the comment period, Dr. N. Alem of UMTRI noted that the error growth rate depends on the integration scheme being used. The UMTRI 3-3-3 array has been found to work very well for "short duration" pulses, but not for "long duration" pulses. The 3-3-3 array has advantages of decreased enhancement of accelerometer resonance in the mounts (for short duration impacts), and it seems to work better for indirect impacts. In the 3-2-2-2 array as used at Wayne State University, cantilever effects produce larger error in vibration than in integration.

5. Frequency Response Studies of Piezoresistive Accelerometers
P.C. Begeman, F.T. Dupont, and A. I. King, Wayne State University

Dr. King discussed the latest work at WSU, exploring the effect of calibration and measurement errors in the 3-2-2-2 nine-accelerometer array. This discussion was limited to response at low frequency.

Manufacturer's calibration data are presented as either dB vs frequency or percent of amplification vs frequency, which makes it difficult to readily determine response error. WSU has calibrated accelerometer arrays on both shaker and rate tables from zero Hz to 200 Hz. They have found the manufacturers' calibrations to be accurate at 100Hz. But measurement sensitivity decreases with frequency, and response error goes to 7% at 0Hz.

An advantage of the 3-2-2-2 array is that the angular acceleration calculations remain stable. Since there are no cross-products, the integration does not "blow up". However, measurement errors are perpetuated through the calculations. WSU did a study of measurement error effects by contrasting double integration calculations of displacement for a "perfect" run and for runs with various pitch, roll, and yaw errors introduced. Details are in the accompanying paper. As a result of the study, WSU concluded that:(1) errors between two accelerometers are most critical, (2) errors between accelerometers must be very much less than 5% (preferably 1%) in order to maintain accuracy, and (3) if all accelerometers in an array have the same error, the integration will remain stable but the error effect will be maximized.

In the comment period, Dr. King noted that the 3-2-2-2 array has been studied with 1-1/2 to 3 inch differences in the leg dimensions. These dimensions were included in the analysis. There was also some technical discussion of manufacturer-supplied calibration curves.

6. Comments on Previous Paper
J. Wilson, Endevco

Mr. Wilson had had an opportunity to review Dr. King's paper in advance, and he presented an accelerometer manufacturer's point of view on the low frequency calibration issue.

Mr. Wilson noted that the reference frequency of 100Hz is used because it is traceable to the National Bureau of Standards. Endevco seldom tries to calibrate accelerometers below 10-20Hz because of calibration problems with the shaker tables. Also, in calibrating accelerometers, Endevco provides percent-sensitivity data at the low-frequency end of the scale and logarithmic (dB) valves at higher frequencies.

Mr. Wilson termed "alarming" the 7-8% deviations at 0Hz as reported by Dr. King. He reported that Endevco's test of a Model 2264 accelerometer had error results of 4% above the 100Hz reference at 0Hz (dc). They also tested a newer design with different construction (Model 7264) and measured almost no error at dc. Mr. Wilson noted that WSU had tested three different designs and had the same results with each. Comparing Endevco's results with these WSU results, Mr. Wilson concluded that WSU was experiencing a systematic calibration error. However, he could not pinpoint the possible source of such an error.

Noting previous discussions on nine-accelerometer array design, Mr. Wilson said he prefers angular accelerometers to either type of nine-accelerometer linear array. He believes that other errors to which the linear array is subject may be greater than the measurement errors discussed at the workshop. It may also be impossible to develop an array with less than one percent total error because of the number of error sources inherent in the design.

During the comment period, Dr. King responded that systematic calibration error was minimized by having three different laboratories conduct the tests. All three measured the same errors, so he belives they are correct. Mr. Wilson was asked if Endevco had done low g tests, in the 10-20g range. He answered that Endevco tested at one g for low frequency response, and at 3-10g for higher frequency response. Endevco did not test their 2000g model accelerometer in the reported test series.

7. <u>An On-Board Digital Data Acquisition System for Impact Tests</u>
P.C. Begeman, F.T. Dupont, and A.I. King, Wayne State University

Dr. Begeman reported on the development at WSU of an on-board, portable digital system for data acquisition. Design goals have been expanded capability, improved data quality (by eliminating cables and analog tapes), improved set-up and turn around time, versatility through compactness and portability, low power demand, ruggedness, and flexibility to handle two types of transducers.

So far, two prototypes have been built. The first is back pack-mounted so a subject can wear it. The unit weighs eleven pounds without batteries, is 6x11x13 inches and has 16 channel capability.

The second is sled-mounted, weighs 24.5 pounds including a 110v power supply, is 8x11x21 inches and has 32 channel capability. The modular design permits mounting of both analog and digital boards in pairs. It features a programmable amplifier, CMOS memory, filters, a 4-channel multiplexer and 10 bit A-D converter with switch-selectable conversion rate. Sample rate is 125-8000 samples per second per channel, and amplifier gain is 4-4096. It is less automated than WSU's ultimate plan, since there is no microprocessor, self-test, or terminal communication capability. To date, this unit has been bench performance tested and debugged. Also, a series of on-board digital vs. off-board analog analyses are being performed. Preliminary results show slightly less noise with the on-board digital system, but otherwise nearly identical results.

Future plans include adding a microprocessor to permit setting gain and sample rate from a terminal, more memory, self calibration and testing, adjustable 2-pole filters, and a master clock instead of one clock per pair of boards.

8. <u>NHTSA Autopsy Reporting Procedure</u>
R. Morgan, NHTSA, A. Hirsch and D. Carroll, Chi Associates

Mr. Morgan briefly introduced a proposed standardized format to be used in reporting post-test autopsy results to NHTSA. The proposed format is included with these proceedings.

Mr. Morgan described the problem NHTSA has in extracting information from the 139 cadaver tests in NHTSA's file. Problems include different reporting formats for each laboratory and ambiguity in terminology and descriptions, with the result that simple inquiries require a large amount of hand effort to answer. NHTSA's goal is a consistent data base management system for handling autopsy data.

The proposed procedure is composed of four sections: (a) General Test Information - date, type of test, etc.; (b) Human Subject Information - anthropometry, appearance, cause of death, etc., with the anthropometry chosen to satisfy requirements of the Calspan CVS model; (c) General Injury Information- data compatible with NASS and computer analysis, consisting of AIS plus injury descriptions by region and location; and (d) Detailed Injury Information - autopsy report, photographs, and diagrams which would be part of a non-computerized hard copy record.

In summary, the format has been formulated, current NHTSA data are being computerized to test the format, and NHTSA is seeking comments and proposed changes to reporting procedures. Copies of the proposed format were distributed to the workshop attendees.

There was an extensive question-and-answer period following Mr. Morgan's presentation. Many questions centered on the extensive anthropometry requirements. It was noted that 37 measures are necessary to satisfy the CVS model. Although Dr. Reynolds needed 68 measures to estimate body segment masses, Mr. Morgan opted for the 37 CVS measurements because an existing NHTSA program (GOOD) can generate mass data given limited anthropometry. The measurements are not considered difficult in a laboratory setting, although NHTSA will specify cadaver positioning more precisely based on some comments from the workshop. Seated measures are for the cadaver as seated pre-test for sled and pendulum tests. In-vehicle measurement schemes need to be developed, but dimensions referred to H-point are preferred. One researcher suggested that, since cadavers necessitate slouched (vs erect) measurements, it would be just as effective to measure the cadaver outside the vehicle and the vehicle seat separately.

A physician researcher commented that the reporting format omits data from the upper extremity and the foot, underemphasizes the neck, spine, and knee, and overemphasizes the pelvis. NHTSA will remedy those situations and was pleased to receive those specific comments. NHTSA will review the method of handling not-applicable pages to prevent unnecessary copying. SI units are not specified but will be eventually, with a pre-processing program used to convert units. The format will fit NHTSA's computerized biomechanics tape format after March 1984, when one tape will be used for both biomechanics and autopsy data.

9. <u>Impact Response of Cadaver Heads</u>
J. A. Newman, Biokinetics and Associates and D. Schneider, University of California at San Diego

Dr. Schneider reported on a series of blunt impact tests to compare head acceleration response between surrogate types. Heads from the Part 572 and Hybrid III ATD's and three human cadavers were struck by a pendulum impactor. The impactor was a 6-inch diameter rigid disc, covered with Ensolite of either 0.9 or .18 inch thickness (to lengthen pulse duration and reduce peak acceleration); impact velocities ranged from 11-17 mph. Three impact conditions were examined - frontal at center of forehead, lateral to skull, and point of chin. Plans to measure acceleration with the Endevco 9-accelerometer unit were not successful because the units could not be mounted solidly on the cadaver heads.

Test results:

a. Frontal - Part 572 head had very high peak g, but this was due to the bottoming-out of the Ensolite pad and thus may not be representative of in-vehicle conditions. Hybrid III and cadaver test results were similar.

b. Lateral - Hybrid III head recorded a lower peak g than Part 572, and cadaver peak g was about 10% lower than Hybrid III, with longer pulse duration. However, the test impacts produced very short pulse durations which may or may not be realistic for automotive crash-related head impacts.

c. Mandibular - The peak g did not vary appreciably with either velocity or surrogate type.

All data were normalized to the average of the cadaver results and compared with the ATD's. For frontal tests, the Part 572 head was similar but the Hybrid III head averaged only 50% of the cadaver heads. In lateral tests, the Part 572 head overestimated cadaver response and the Hybrid III slightly underestimated. In mandibular tests, both ATD's overestimated head acceleration, but his result is not surprising since the ATD heads do not have articulated mandibles.

Dr. Schneider concluded by noting that their tests showed under the specified impact conditions some basic differences in response between ATD and cadaver skulls. These results leave many unanswered questions about the reasons for the differences, the applicability of laboratory test conditions to actual automotive crash conditions, the effect of different pulse durations and uncontrollable variables inherent in cadaver testing.

An extensive question/answer/comment period followed the presentation. One researcher commented that MVMA is reexamining the Hodgson head impact data which formed the basis for the Wayne State Tolerance Curve. He asked Dr. Schneider about repeated impacts, temperature effects and head masses. Head mass varied from 9.4 to 12.7 pounds for the three cadaver heads which were separated at C-1 and had some neck muscle attached. Soft tissues were at room temperature for testing because of lengthy set-up time. Each cadaver head was impacted multiple times, and no attempt was made to quantify possible deterioration of bone or soft tissue (the impactor padding was thought to minimize this effect). They did not attempt to examine embalming effects, except to note that there were no obvious response differences between embalmed and unembalmed subjects. No bone fractures were noted in any test - the skulls remained intact throughout the test program. They did not attempt to pressurize the skulls, but another researcher commented that pressurization might affect results because the brain may then be coupled to the skull.

In answer to a question about the type of "Ensolite" used, Dr. Schneider offered that it may be advantageous to publish a load-deflection curve for padding with the test results. He could not comment on possible adjustments in the normalization method for the variations in head mass compared to a constant impactor mass (the co-author did the normalization and he could not be present at the workshop).

Dr. Schneider agreed that peak acceleration may not be the best parameter for surrogate comparisons. Other possibilities are pulse duration, HIC, or average acceleration. They calculated HIC, and did not have substantially different conclusions. They did not measure impact force because the project was not funded for it.

10. <u>Insufficiency of HIC as a Measure of Impact Severity</u>
T. B. Khalil and D. C. Viano, GM Research Laboratories

Dr. Khalil began by outlining the reasoning behind the Head Impact Criterion - an object is impacted with force, the acceleration response is measured and an attempt is made to relate that response to physical phenomena associated with injury. However, biomechanics researchers are still not in full agreement that acceleration is the best indicator of injury.

Dr. Khalil emphasized that there are still two schools of thought on the source of head injury - translation and rotation. If acceleration is related to injury, both translational and rotational accelerations become important. However, the HIC, which is traceable to the Wayne State Tolerance Curve, is primarily a translational acceleration measure.

Work by Hirsch and Ommaya concluded that concussion or head injury was due to rotation about the head CG and associated shear strains within the skull contents. However, because the rotation axis is difficult to locate and specify, and because rotation cannot be measured in a straight-forward manner, it is largely ignored in injury tolerance definitions.

Dr. Khalil analyzed HIC in a way to account for both rotational and translational components. He concluded that HIC is a non-linear curve and highly dependent on the measurement point in the head. Proximity of the measurement point to the CG of the head is especially critical. He then developed a series of curves for varying pulse durations which can be used to determine the combination of angular and linear accelerations resulting from the impact.

He concluded that HIC currently does not account for rotation, and therefore it is not sufficient to characterize the injurious effects of impact throughout the head.

Having reopened the issue of translation vs. rotation as a source of head injury, Dr. Khalil's paper generated substantial discussion. He was asked if his and Ommaya's definition of rotation are the same; they are according to his analysis of Ommaya's data. The Hirsch/Ommaya data may not have been completely accurate in an absolute sense, but they did point out trends with their experiments. They were able to virtually eliminate translation in most tests, according to Dr. Khalil.

The influence of accelerometer location relative to CG was discussed. Most data sets probably have a mixture of both translation and rotation. The degree of each component is generally unknown, but the complex motion can be decomposed using Khalil's method and a nine-accelerometer array. HIC accounts only for translation of the CG, although this can be a curvilinear motion. Dr. Viano, the co-author, observed that accelerometer placement in dummy heads is off the CG and therefore does include rotation. However, mathematical simulations do use the true head CG and therefore may not account for considerable rotation effects.

Dr. Khalil noted that a method needs to be developed to separate out the acceleration components so that the injury-causing potential of each may be examined. An NHTSA attendee closed the discussion by noting that French researchers have been working on a more sophisticated rotational acceleration analysis and have submitted new materials to ISO. He observed that it may be necessary to examine the entire issue again in the future.

11. Bone Ash Studies - Experimental Procedure (General Discussion)

To complete the 1983 Workshop, the participants were invited to discuss procedures to determine ash content of bone in proposed cadaver test subjects. Biomechanics researchers have been trying for years to develop methods of categorizing cadaver skeletal condition (see previous workshop proceedings for descriptions of bending and crush tests and other methods). NHTSA has proposed using bone ash content as a determinant of bone condition. They requested a discussion period at this Workshop to agree on experimental procedures to be used in measuring ash/bone ratios.

To begin the discussion, Dr. D. Got of the Biomechanics and Accidentology Research Institute, Raymond Poincaré Hospital, Garches, France, reported on an extensive bone ash study which he is directing. He described the method as inexpensive and quick: a bone sample is reduced to ash by exposing it to 700°C for two hours. He has tested bone samples from 145 cadavers: 2 pieces of rib, 4 of skull, 3 of femur, 2 of tibia, and a whole C3 or C6 vertebra. He finds that mineralization varies by a factor of five.

(The first procedure attempted by Dr. Got involved measuring the relative percentages of cortical vs medullary bone from a bone cross-section. However, it was too difficult to separate out the bone types, especially in osteoporitic specimens, and the whole procedure was too time-consuming).

Some encouraging results were reported. Dr. Got found excellent correlation in the bone ash test ($r = .99$) for fresh weight vs cortical bone content in the femur. These results do not apply to rib because ribs contain a large percentage of medullary bone. Good correlation was also found between two samples from different parts of the same bone (applies to tibia, skull, 4th and 11th ribs from same person). For reasons noted above, rib content does not correlate with skull ($r = .12$) or femur. Therefore, Dr. Got concludes that bone condition should not be predicted by crossing body regions.

Morphological study techniques were compared to mineralization techniques. Good correlation ($r = .93$) is achieved between bone volume and ash content. Since bone surface measurement to calculate volume is not practical, the ash content technique would be preferred. Also, shear energy correlates ($r = .83$) to mineral content for skull and rib samples.

Dr. Got concluded his remarks by observing that bone ash content is a good measurement to make, but care is needed to be sure no other portions of the fragment remain prior to starting the burn (must bake out moisture and fatty marrow first). When properly prepared, bone ash content for healthy bone is 30-40% of original fresh weight. Severely osteoporitic bone is as low as 7%, but the volume of lipids and water in such bone is even more variable than that of healthy bone.

Discussion continued from the floor. Initial discussion centered on the need for a standardized test procedure and the "fresh weight" of the sample which is incinerated to obtain ash. Since the major interest from a biomechanics standpoint is in knowing how much bone the specimen contains, the definition of what sample is to be incinerated is very important. Unfortunately, a measurement of "fresh weight" has no morphological or biomechanical correlation.

One researcher asked why there was no correlation found between flat bones in the rib and the skull. Dr. Melvin answered by referencing an HSRI study which showed that the skull bones do not change with age as other bones do.

There was much discussion about the significance of the bone ash test and how it might complement other possible tests. "Normal" results from a bone ash test, according to Dr. Got, are defined by calcium salts. The density of calcium salts is 1 gm/cc of compact bone in males and 1.25 gm/cc in females (healthy individuals). Therefore, bone ash test results are related to the true volume of load-bearing bone, and the results should be useful in prescreening cadavers. The screening quantity recommended by Dr. Got is percent weight of salts per volume of bone, but the selection of bone sample is not yet defined or standardized.

The bone ash test should complement the mechanical bending test of a rib segment according to some participants. The ash test could assist in prescreening because it can be performed before an impact test (by using the 11th rib) and because it is an indicator of skeletal system quality. Post-impact, the bending test is valuable because it produces a mechanical quantity which is related to physical dimensions. Dr. Kallieris, University of Heidelberg, referred the Workshop to his comparison of bending test and mineral salt content which was presented at the 1982 Workshop [Proceedings of Tenth Annual Workshop, p.17]. He tested 76 pairs of ribs over an age range of 15-69 years and got good correlation between the two types of tests.

Two participants commented on the need to establish standardized procedures so that the appropriateness of bone tests in cadaver selection can be fairly evaluated. It is also necessary to have standardized data to establish scaling or other methods which may be used to relate a proposed test specimen to the "normal" or other populations.

Another researcher observed that it will be necessary to differentiate between absolute strength of a bone sample and bone quality, since a normal, healthy bone might be structurally weak merely because of its size. He suggested, and the participants agreed, that a better quantity to examine is mass of bone ash as a percent of original bone volume.

The discussion was ended with the establishment of an ad-hoc committee of the workshop to develop a standardized procedure for conducting bone ash/mineralization tests. This type of committee has had previous success in establishing consensus among researchers who conduct biomechanical testing with human surrogates. The ad-hoc committee members are, Mr. Morgan, NHTSA, secretary, and Drs. Got, Walsh, Kallieris, Melvin and Cheng. The committee will prepare and circulate its recommendations so that a standarized mineralization test procedure can be adopted at the next workshop.

The Workshop adjourned at approximately 4:30 p.m. The Twelfth International Workshop will be held in Chicago, Illinois, in November 1984, in conjunction with the 28th Stapp Car Crash Conference.

DAVID R. FOUST
Recorder