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Hybrid III Patella-Femur-Pelvis Response to Pendulum, Sled, and Vehicle Impact

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ABSTRACT This study examines 100 Hybrid III experiments in which the lower extremities are dynamically loaded. A number of the Hybrid III dummy experiments are vehicle crashes with recent model cars. A range of response of the Hybrid III in the vehicle crash tests is determined.

In the rest of the experiments, Hybrid IIIs are tested in pendulum or sled tests. The response of the sled and pendulum Hybrid III tests are compared with the vehicle Hybrid III tests.

INTRODUCTION Previous studies [1, 2, 3] of femur response have concluded that there is a considerable difference between the Part 572 dummy and cadaver relative to the magnitude and duration of femur loading in all but soft structures.[4][1] More recently, Foster [5] discerned the Hybrid III femur to be closer to cadaveric responses than the Part 572 but Viano [6] found the Hybrid III to still be lacking.

Relative to patella-femur-pelvis injury, a body of research [7, 8, 9, 10, 11, 12] indicates that a reasonable femur injury criterion to prevent bone damage is to limit the axial compressive load to less than 2250 lbs. (10.0 kN). Viano [13] suggested a 2000 lb. femur load be considered a static portion of the criterion and that higher loads be allowed for cases where the duration of the femur force is less than 20 msec. In other words, Viano defined a permissible knee force as:

$F_{femur}(lb) = 5200 - 160\ T_{pulse}$ when $T_{pulse} < 20$ msec

$F_{femur}(lb) = 2000$ when $T_{pulse} >= 20$ msec

The data used in Reference 13 are mostly pendulum impacts to the patella-femur-pelvis complex.

In 1983, Leung et al. [14] presented the results of 16 cadaver tests performed in a vehicle body mounted on a sled. A formulation similar to the Viano criterion was found to separate injury from non-injury. The tolerance to fractures was found to depend on the cadaver subject's bone condition.

PROCEDURE The information used in this study is a subset taken from the

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[1]Numbers in brackets designate references at end of paper.

National Highway Traffic Safety Administration's (NHTSA) Biomechanics Data Base. Over the past seven years, the agency has been systematically collecting the data from the biomechanical tests performed in different experimental programs and storing the knowledge in one central repository. Currently, the total data bank holds the records of 615 human cadaver, 343 human volunteer, and 1333 dummy dynamic impacts conducted over 14 years from 1975 to 1988. The test type of the entire data bank ranges from component to whole body sled to vehicle crash tests while the impact direction varies mostly from anterior-posterior to medial-lateral. The experimental data (accelerometers, force, deflection, etc.) time histories are preserved on magnetic tape and rapidly read into the computer when needed for analysis.

In all tests used in this study, the impact was frontally into the Hybrid III dummy patella-femur-pelvis complex loading through the patella.

After the data was selected, it turned out that the Hybrid III pendulum and sled impact data was associated with four agency-sponsored studies [15, 16, 17, 18, 19].[2] Many of these pendulum and sled tests had cadaver impacts coupled with them under the identical test conditions. It is not the object of the current paper to discuss these cadaver tests. Since 1982, 67 Hybrid III Dummies underwent testing in nine different vehicle makes and models. Some vehicles were crashed into a rigid barrier at 35-mph while others were vehicle-to-vehicle full-frontal smashups at 60-mph. Unfortunately, there no analogous cadaver tests in these vehicles. In other words, the data set we shall examine in the following pages is composed of (1) Hybrid III pendulum tests, (2) Hybrid III sled tests, and (3) Hybrid III vehicle crash tests.

PROCESSING OF DATA TRACES The purpose of this section is to discuss four aspects of electronic data processing: type of transducers used, frequency content of data, quality screening, and the approach taken to calculate force time duration.

The analyses to be performed used electronic time histories collected during each test. These data include external force applied at the patella (not measured in the vehicle crashes), and internal force in the femur (measured in all Hybrid III tests, save one).

Every effort was made to use data which had SAE Class 1000 data specifications. All accelerations were subsequently processed with an SAE Class 180 filter (the particular digital filter was a two pass, zero phase shift, second order Butterworth filter). The SAE recommended filter for the femur is Class 600. To the eyes of at least one of the authors, many of the Class 600 femur force traces appeared "spiky" and looked like the "raw" traces (the Class 1000 traces). Consequently, all femur force data were processed with a Class 180 filter.

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[2]References 17 and 18 cover the same experiments.

All data traces were screened for quality by: (1) checking to see if all specification data was correct and complete and (2) looking for traces that imply disagreement with physical principles, e. g., seeing if integration of the sled acceleration gave a value many times greater than the recorded sled velocity (in which case the sled acceleration is suspect).

Many investigators in the literature (e. g., References 3, 6, 11, 13, 14, and 18) found it beneficial to employ the primary pulse duration of the knee applied force (T_{pulse}) while investigating femur injury. The method used to determine the primary pulse duration appears to vary from study to study. A goal of this current analysis was to use an algorithm which could be coded on the computer and used during the processing of the data time histories. To determine the pulse duration, Leung [14] used an algorithm in which the impulse is divided by the peak force. Donnelly [18] used a pulse duration algorithm in which the peak is first determined; and then the times -- to the left side and right side of the peak force -- at 1/5th of the peak force are calculated. In the present study, the pulse duration is determined as the difference of the two times at 1/8th of the peak force as shown in Figure 1. The logic for the "1/8" choice goes as follows. Both the Leung and Donnelly algorithms are robust in that they work in a straightforward manner for the femur force curves in the data set. The choice of which is "best" is somewhat arbitrary. The Donnelly algorithm seemed to be closer to what was subjectively chosen as an approximation of the femur force curve pulse duration. For that reason, we chose to follow the 1/5th of the maximum force approach. For some of the curves, even the 1/5 approach gave pulse duration numbers which were shorter than what would be a subject choice. For the present data, we found the algorithm was still robust when the two time marks were determined by 1/8th of the peak femur force. If the fraction is chosen slightly below 1/8th, the algorithm begins to fail, i. e., begins to choose the last data point as one of the time marks.

DESCRIPTION OF EXPERIMENTAL SETUPS The vehicle crash tests with Hybrid III occupants were conducted at Dynamic Science, Transportation Research Center, and General Motors. Dummies were seated in the driver or the passenger seat of recent model cars and were either unrestrained or restrained by a manual 3-point or automatic 2-point belt system. A summary of the vehicles, crash conditions, and dummy readings is found in Table 1.

The experimental setup of the first of two sled test studies conducted at Wayne State University [15] is shown in Figure 2. The thoracic region was restrained by a nonventing air bag on a nonstroking column. The lower extremities were restrained by aluminum hexcel pads. Behind each separate aluminum hexcel pad was a uniaxial load cell which measured the force interaction with the patella (denoted as applied femur force herein). Hybrid III Dummies were tested in this experimental arrangement. The Hybrid III experiments had load cells behind the aluminum hexcel pads and a triaxial acceleration mount in the pelvis (there were no internal femoral load cells in the Hybrid III used in Reference 15). A summary of all the Hybrid III pendulum and sled tests is in Table 2. The experiments in the sled body of Figure 2 are identified in Table 2 by a Test Number beginning with the letter 'A.'

The experimental setup of the second set of Wayne State University sled tests [16] is illustrated in Figure 3. The upper torso was restrained by a 2-point belt and each separate lower extremities hit a separate energy-absorbing knee bolster. Behind each separate knee bolster was a 2-axis load cell whose output could be resolved into a resultant applied femur force. The agency sponsored the Wayne State University study using cadavers only. Hybrid III tests in the identical sled were sponsored by Ford Motor Company and were made available to the Biomechanics Data Base courtesy of Ford. The Hybrid IIIs had femoral load cells and a triaxial accelerometer package at the pelvis. The experiments in the sled body of Figure 3 are identified in Table 2 by a Test Number beginning with the letter 'W.'

At Calspan, each cadaver leg was separately impacted on the patella by a flat face pendulum. [17, 18] Each leg was struck separately in the pendulum experiments as shown in Figure 4; unlike the sled trials in which both legs were loaded simultaneously. The applied femur load was determined from an accelerometer mounted on the pendulum. Hybrid IIIs had internal femoral load cells but no pelvis accelerometers. The pendulum experiments are denoted by the letter 'C' in Table 2.

The sled tests performed at the University of California at San Diego (UCSD) [19] were conducted in a sled buck -- shown in Figure 5 -- which is based on a 1983 Chevrolet Citation. Each lower extremity of the "unrestrained" occupant was controlled separately by deformable blocks of semirigid polyurethane foam. Behind both the right and left block were three uniaxial load cells from which a resultant applied femur load was computed. The Hybrid IIIs had both femoral load cells and pelvic triaxial accelerometers. The UCSD sled tests are denoted by the letter 'S' in Table 2.

<u>ANALYSIS OF HYBRID III TESTS</u> The crash tests listed in Table 1 are of two types: vehicle-to-vehicle and vehicle-to-barrier. A scatter plot of the Hybrid III internal force versus pulse duration is exhibited in Figure 6 for the vehicle-to-vehicle tests. Obviously, the average of the internal femur force for the 3-point belt restrained Hybrid IIIs is lower than for the unrestrained Hybrid IIIs. No 3-point belt restrained Hybrid III has a force higher than the very low 2000 pound level. The unrestrained Hybrid III force readings range from low to a level noticeably higher than the low 2000 pounds.

A scatter plot for the combined vehicle-to-vehicle and vehicle-to-barrier crash tests (i. e., all the data points of Table 1) is constructed in Figure 7. The same observations noted for Figure 6 seem appropriate for Figure 7.

There are two types of belt restraints shown in Figure 7: a 3-point manual belt and a 2-point automatic belt. Figure 8 shows only the belt restrained data points from Figure 7 (i. e., the unrestrained Hybrid IIIs have been omitted). The average internal femur force for the 2-point restrained occupants is slightly higher than for the 3-point restrained occupants; but in general, there is not a clear separation of the femur loads for the two restraint types.

Recently, there have been suggestions (internal discussions in the NHTSA and in open discussion at the Stapp Conference following the presentation of Reference 18) that cadaver pendulum experiments are not particularly helpful because they are disparate with the patella/instrument-panel impact loading patterns observed in real world vehicle crashes. Perhaps a reasonable question is, "Given the Hybrid III Dummies perform in the vehicle crash tests within a certain region, do the pendulum-to-patella impacts to the Hybrid III respond within that same region ?" A reasonable point to begin might be the Viano femur injury criterion formulation of Reference 13. This formulation, of course, relates fracture to peak cadaver applied femur force and femur force pulse duration. For the data in Table 1, it is possible to define a region (a rectangle) for current model vehicle crash tests -- as in Figure 9 -- within which we expect 95% of the peak Hybrid III femur forces and 95% of the Hybrid III peak force time durations to fall.

Examining Figure 10, a plot of all the Hybrid III peak internal femur force versus the corresponding femur force pulse duration for the vehicle crash tests, proves the femur force and pulse duration vary over a rather wide range. The two vertical lines represent the plus and minus 2 sigma limits on the pulse duration values and suggest that within the two lines we might expect 95% of the observations to fall. The horizontal line, about 2,700 pounds, is the plus 2 sigma line for the femur force. The lower 95% line on the peak femur force was a negative number (-59 pounds) which is physically impossible for the compression loads observed. Consequently, the lower line of the expected values rectangle was arbitrarily drawn at the horizontal axis. The four lines represent a region where we would expect a large percentage of Hybrid III readings to fall when exposed to a crash test in a current model vehicle.

Figure 11 is a plot of all Hybrid III peak internal femur force versus the corresponding femur force pulse duration for the pendulum impacts and sled tests. The integers represent ten different test conditions and are explained in Table 3. The pendulum impacts are represented by the integers 1, 2, and 3; and fall outside of the expected region of response for vehicle crashes. The sled test condition represented by the integer "9" is shown in Figure 11 as clustered with the pendulum tests. The pulse width of the accelerometer of the test condition "9" is much shorter (i.e., about 70 msec) than the other sled conditions. The other sled tests, fall within the expected region of response for vehicle crashes. This means that pendulum hits load the Hybrid III differently than vehicle crashes; and the Hybrid III in sled runs generally responds within a femur-force/pulse-duration region expected in a car crash.

CONCLUSIONS

- As measured in current model vehicle crash tests, the Hybrid III femur load cells responds as follows: (1) the SAE Class 180 filtered force ranges up to 2,700-pounds and (2) the force pulse duration ranges between 8 and 100-msec. This statement is based on the aggregate of all the (1) unrestrained, (2) 3-point belt restrained, and (3) 2-point automatic belt restrained Hybrid IIIs tested in the vehicles.

- Hybrid III femurs in sled tests generally respond similarly to the Hybrid IIIs in the vehicle crash tests. Hybrid III femurs in pendulum tests do not behave physically as Hybrid IIIs in vehicle crash tests.

ACKNOWLEDGMENTS The Hybrid III runs which match the four cadaver test configurations of Reference 16 were provided as a courtesy by Ford Motor Company.

DISCLAIMER The views presented are those of the authors and are not necessarily those of the National Highway Traffic Safety Administration, U. S. Department of Transportation.

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TABLE 1

HYBRID III VEHICLE TESTS

Test No.	Closing Speed (msec)	Restraint Used	Vehicle Make	Vehicle Model	Veh Year	Internal Femur Force (lbs)	Internal Pulse Duration (msec)	Occupant Location (vehicle number)
CAR TO CAR								
V611-L	62	None	Dodge	Omni	83	1955	50	Passenger(2)
V630-L	63	None	Renault	Fuego	83	3757	40	Passenger(2)
V630-R	63	None	Renault	Fuego	83	3016	34	Passenger(2)
V631-R	63	None	Honda	Accord	83	3426	31	Passenger(2)
V631-L	63	None	Honda	Accord	83	2756	76	Passenger(2)
V645-R	62	None	Chevrolet	Celebrity	83	1670	52	Passenger(2)
V645-L	62	None	Chevrolet	Celebrity	83	2147	53	Passenger(2)
V785-L	60	None	Honda	Accord	84	1032	62	Driver(1)
V785-R	60	None	Honda	Accord	84	2042	48	Driver(1)
V785-L	60	None	Honda	Accord	84	1615	72	Passenger(2)
V785-R	60	None	Honda	Accord	84	1655	61	Passenger(2)
V795-L	60	None	Dodge	Omni	83	1004	54	Driver(1)
V795-R	60	None	Dodge	Omni	83	1291	56	Driver(1)
V795-L	60	None	Dodge	Omni	83	1062	59	Passenger(2)
V795-R	60	None	Dodge	Omni	83	1948	53	Passenger(2)
V796-L	60	None	Renault	Fuego	83	2559	62	Driver(1)
V796-R	60	None	Renault	Fuego	83	1366	56	Driver(1)
V796-L	60	None	Renault	Fuego	83	2132	48	Passenger(2)
V796-R	60	None	Renault	Fuego	83	2672	43	Passenger(2)
V804-L	60	None	Honda	Accord	84	1394	67	Driver(1)
V804-R	60	None	Honda	Accord	84	956	46	Driver(1)
V804-L	60	None	Honda	Accord	84	2008	71	Passenger(1)
V804-R	60	None	Honda	Accord	84	1489	54	Passenger(1)
V804-L	60	None	Renault	Fuego	82	1628	58	Driver(2)
V804-R	60	None	Renault	Fuego	82	983	64	Driver(2)
V804-L	60	None	Renault	Fuego	82	2302	44	Passenger(2)
V804-R	60	None	Renault	Fuego	82	2151	50	Passenger(2)
V812-L	56	3PT	Honda	Accord	84	585	59	Driver(1)
V812-R	56	3PT	Honda	Accord	84	535	18	Driver(1)
V812-L	56	None	Honda	Accord	84	2303	61	Passenger(1)
V812-R	56	None	Honda	Accord	84	1743	51	Passenger(1)
V812-L	56	None	Chevrolet	Celebrity	84	776	89	Driver(2)
V812-R	56	None	Chevrolet	Celebrity	84	472	58	Driver(2)
V812-R	56	3PT	Chevrolet	Celebrity	84	255	21	Passenger(2)
V815-L	55	3PT	Honda	Accord	84	551	44	Driver(1)
V815-L	55	None	Honda	Accord	84	2700	54	Passenger(1)
V815-R	55	None	Honda	Accord	84	2288	31	Passenger(1)
V815-L	55	None	American	Concord	82	1300	41	Driver(2)
V815-R	55	None	American	Concord	82	1758	24	Driver(2)
V815-L	55	3PT	American	Concord	82	400	40	Passenger(2)
V815-R	55	3PT	American	Concord	82	306	46	Passenger(2)
V816-L	55	3PT	Dodge	Omni	83	680	17	Driver(1)
V816-R	55	3PT	Dodge	Omni	83	641	17	Driver(1)
V816-L	55	None	Dodge	Omni	83	1334	58	Passenger(1)
V816-R	55	None	Dodge	Omni	83	1555	52	Passenger(1)
V816-L	55	None	American	Concord	82	1140	33	Driver(2)
V816-R	55	None	American	Concord	82	1577	40	Driver(2)
V816-L	55	3PT	American	Concord	82	309	40	Passenger(2)

TABLE 1 (CONT.)

V824-R	57	None	Renault	Fuego	83	1866	42	Passenger(1)
V824-L	57	None	Chevrolet	Celebrity	83	1892	49	Driver(2)
V824-R	57	None	Chevrolet	Celebrity	83	1204	62	Driver(2)
V845-R	60	3PT	Dodge	Omni	83	2016	16	Driver(1)
V845-L	60	3PT	Dodge	Omni	83	739	96	Driver(1)
V845-L	60	3PT	Dodge	Omni	83	417	17	Passenger(2)
V845-R	60	3PT	Dodge	Omni	83	322	58	Passenger(2)
V845-L	60	None	Dodge	Omni	83	1754	75	Driver(2)
V845-R	60	None	Dodge	Omni	83	1579	21	Driver(2)
V860-L	59	3PT	Honda	Accord	84	1453	88	Driver(1)
V860-R	59	3PT	Honda	Accord	84	654	10	Driver(1)
V860-L	59	None	Honda	Accord	84	2258	81	Driver(2)
V860-R	59	None	Honda	Accord	84	672	48	Driver(2)
V860-L	59	3PT	Honda	Accord	84	405	27	Passenger(2)
V860-R	59	3PT	Honda	Accord	84	304	52	Passenger(2)
V864-L	59	None	Renault	Fuego	83	1534	108	Driver(2)
V864-R	59	None	Renault	Fuego	83	1731	27	Driver(2)
V865-L	59	None	Honda	Accord	84	864	83	Passenger(1)
V865-R	59	None	Honda	Accord	84	393	22	Passenger(1)
V865-L	59	3PT	Honda	Accord	84	1306	137	Driver(1)
V865-R	59	3PT	Honda	Accord	84	1182	37	Driver(1)
V865-R	59	3PT	Renault	Fuego	83	402	28	Driver(2)
V865-L	59	None	Renault	Fuego	83	1551	65	Passenger(2)
V865-R	59	None	Renault	Fuego	83	518	54	Passenger(2)
V866-L	54	3PT	Chevrolet	Celebrity	83	350	98	Driver(2)
V866-R	54	3PT	Chevrolet	Celebrity	83	653	23	Driver(2)
V877-L	60	None	Dodge	Omni	83	931	65	Driver(1)
V877-R	60	None	Dodge	Omni	83	952	34	Driver(1)
V877-L	60	None	Dodge	Omni	83	1005	28	Passenger(2)
V877-R	60	None	Dodge	Omni	83	1365	55	Passenger(2)
V974-L	51	None	Chevrolet	Cavalier	84	742	91	Driver(1)
V974-R	51	None	Chevrolet	Cavalier	84	969	86	Driver(1)
V974-L	51	None	Chevrolet	Cavalier	84	847	67	Driver(2)
V974-R	51	None	Chevrolet	Cavalier	84	1074	56	Driver(2)
V974-L	51	None	Chevrolet	Cavalier	84	1070	64	Passenger(2)
V974-R	51	None	Chevrolet	Cavalier	84	1791	62	Passenger(2)
V974-L	51	None	Chevrolet	Cavalier	84	1073	74	Passenger(1)
V974-R	51	None	Chevrolet	Cavalier	84	1126	85	Passenger(1)
V976-L	51	None	Chevrolet	Cavalier	84	1057	92	Driver(1)
V976-R	51	None	Chevrolet	Cavalier	84	1005	72	Driver(1)
V976-L	51	None	Chevrolet	Cavalier	84	1118	66	Passenger(1)
V976-R	51	None	Chevrolet	Cavalier	84	1556	69	Passenger(1)
V976-L	51	None	Chevrolet	Cavalier	84	838	82	Driver(2)
V976-R	51	None	Chevrolet	Cavalier	84	1467	42	Driver(2)
V976-L	51	None	Chevrolet	Cavalier	84	1264	59	Passenger(2)
V976-R	51	None	Chevrolet	Cavalier	84	1804	68	Passenger(2)

CAR TO BARRIER

V773-L	30	None	Chevrolet	Celebrity	83	1244	85	Driver
V773-R	30	None	Chevrolet	Celebrity	83	1132	40	Driver
V776-L	30	None	Chevrolet	Celebrity	83	160	96	Passenger
V779-L	30	None	Pontiac	Fiero	84	1110	57	Driver
V779-R	30	None	Pontiac	Fiero	84	1163	47	Driver
V783-L	30	None	Pontiac	Fiero	84	1496	57	Passenger
V783-R	30	None	Pontiac	Fiero	84	2292	62	Passenger
V819-L	30	3PT	Honda	Accord	84	1049	55	Driver

TABLE 1 (CONT.)

V846-R	30	3PT	Dodge	Omni	83	691	18	Driver
V846-L	30	None	Dodge	Omni	83	1882	77	Passenger
V846-R	30	None	Dodge	Omni	83	1007	48	Passenger
V847-L	30	None	Renault	Fuego	83	1731	51	Passenger
V847-R	30	None	Renault	Fuego	83	1856	55	Passenger
V848-L	30	2PT	VW	Rabbit	84	1223	59	Driver
V848-R	30	2PT	VW	Rabbit	84	1050	55	Driver
V848-L	30	2PT	VW	Rabbit	84	1724	50	Passenger
V848-R	30	2PT	VW	Rabbit	84	1187	54	Passenger
V859-L	30	2PT	VW	Rabbit	82	1459	45	Driver
V859-R	30	2PT	VW	Rabbit	82	1407	45	Driver
V859-L	30	2PT	VW	Rabbit	82	1681	57	Passenger
V859-R	30	2PT	VW	Rabbit	82	1247	56	Passenger
V873-L	30	3PT	Honda	Accord	84	986	80	Driver
V876-L	30	3PT	Dodge	Omni	83	468	26	Driver
V876-R	30	3PT	Dodge	Omni	83	264	49	Driver
V903-L	30	2PT	VW	Golf	86	891	138	Driver
V903-R	30	2PT	VW	Golf	86	1607	33	Driver
V975-L	26	None	Chevrolet	Cavalier	84	1072	68	Driver
V975-R	26	None	Chevrolet	Cavalier	84	1046	53	Driver
V975-L	26	None	Chevrolet	Cavalier	84	1134	61	Passenger

All forces were processed with an SAE Class 180 filter.

TABLE 2

HYBRID III SLEDS AND PENDULUMS

Test Number	Test Type	Initial Velocity (mph)	Internal Femur Force (lbs)	Internal Femur Impulse (lbs/sec)	Internal Pulse Duration (msec)	Applied Femur Force (lbs)	Applied Femur Impulse (lbs/sec)	Applied Pulse Duration (msec)	Pelvi Acc Result (g's
WAYNE STATE UNIVERSITY (Figure 2 and Ref. 16)									
A81030	BAG	30				2589	65	39	
A81130	BAG	30				2036	37	31	
WAYNE STATE UNIVERSITY (Figure 3 and Ref. 17)									
W85001	R100	29	1827	26	24	2881	79	29	
W85101	R100	29	1866	31	39	2355	83	40	
W85005	R60	30	2350	32	19	4074	80	22	
W85105	R60	30	2432	29	17	3650	80	22	
W85009	R60h	30	5440	35	12	7533	100	15	
W85109	R60h	30	4978	40	12	6827	85	11	
W85011	R100L	30	1475	25	26	3227	85	33	
W85111	R100L	30	1596	28	30	3127	67	30	
CALSPAN CORPORATION (Figure 4 and Refs. 18,19)									
C87001	PENR	9							
C87101	PENR	9	2998	14	4	2947	21	5	
C87002	PENR	9							
C87102	PENR	9	2929	14	4	2944	22	5	
C87003	PENR	9	2924	14	4	2853	22	5	
C87103	PENR	9							
C87004	PENR	9	2876	14	4	2941	22	5	
C87104	PENR	9							
C87005	PENP	9	1554	12	15	1981	21	14	
C87105	PENP	9							
C87006	PENP	8	1607	14	14	1953	21	15	
C87106	PENP	8							
C87007	PENP	8	1611	15	16	1962	21	16	
C87107	PENP	8							
C87008	PENP	8	1595	13	14	2042	22	13	
C87108	PENP	8							
C87010	PENP	8							
C87110	PENP	8	1873	13	12	2135	22	12	
C87011	PENP	16							
C87111	PENP	16	5239	22	4	4685	39	5	
C87012	PENR	6	968	6	7	964	10	8	
C87112	PENR	6							
C87013	PENR	5	1033	6	7	1131	10	8	
C87113	PENR	5							
C87014	PENR	5	1015	6	7	1041	10	8	
C87114	PENR	5							
C87015	PENR	3	524	5	11	625	7	11	
C87115	PENR	3							
C87016	PENR	3	553	8	11	629	7	11	
C87116	PENR	3							
C87017	PENR	13	3717	16	3	3247	27	6	
C87117	PENR	13							
C87018	PENR	13	3876	16	3	3554	27	5	

TABLE 2 (CONT.)

C87118 PENR	13							
C87019 PENR	15	5868*	22	3	5497	41	5	
C87119 PENR	15							
C87020 PENR	17	6436*	25	3	5985	42	5	
C87120 PENR	17							
UNIVERSITY OF CALIFORNIA AT SAN DIEGO (Figure 5 and Ref. 20)								
S85013 SW	21	588	31	72	1068	41	64	
S85113 SW	21	556	24	70	1014	43	72	
S85014 SW	21	557	27	66	1206	41	59	
S85114 SW	21	487	24	70	1320	43	62	
S85015 SW	16	395	16	56	816	32	70	
S85115 SW	16	465	22	69	779	32	63	
S85016 SW	15	444	17	55	559	24	64	
S85116 SW	15	394	17	60	761	28	68	
S85017 SW	27	1874	47	68	2420	70	66	
S85117 SW	27	1392	34	67	2544	57	58	
S85018 SW	25	2483	44	42	3264	71	54	
S85118 SW	25	1088	33	65	2205	55	59	
S85019 SW	25	2126	41	59	2367	62	56	1
S85119 SW	25	2496	36	33	3372	61	35	1

Bag = Sled test equipped with non-venting bag
R100 = Sled with a passive 2 point belt system and a bolster at a 100-deg knee angle run at 22g's
R100L = Sled with a passive 2 point belt system and a bolster at a 100-deg knee angle run at 22g's (low knee bolster; see ref.17, pg.102)
R60 = Sled with a passive 2 point belt system and a bolster at a 60-deg knee angle run at 22g's
R60h = Sled with a passive 2 point belt system and a bolster at a 60-deg knee angle run at 35g's
PENR = Pendulum rigid
PENP = Pendulum padded
SW = Sled with energy absorbing steering wheel

All forces and accelerations were processed with an SAE Class 180 filter.

* estimated graphically by extrapolation

TABLE 3

Hybrid III Symbol	Test Configuration
1	54 Square Inch Flat Plate with Two Inch Polyurethane Foam Pad run at 17mph.
2	54 and 80 Square Inch Flat Plate run at 9mph. (See appendix B)
3	28,54 and 80 Square Inch Flat Plate run at 17mph. (See Appendix B.)
4	Sled With an Energy Absorbing Steering Wheel run at 15mph.
5	Sled With an Energy Absorbing Steering Wheel run at 21mph.
6	Sled With an Energy Absorbing Steering Wheel run at 25mph.
7	Sled With a Passive 2 Point Belt System And a Bolster at a 100-degree Knee Angle Run at 30mph (22 g).
8	Sled With a Passive 2 Point Belt System And a Bolster at a 60-degree Knee Angle Run at 30mph (22 g).
9	Sled With a Passive 2 Point Belt System And a Bolster at a 60-degree Knee Angle run at 30mph but at a higher g-level (35 g).
10	Sled With a Passive 2 Point Belt System And a Bolster at a 100-degree Knee Angle Run at 30mph (22 g). (Low knee bolster see ref.17, pg.102)
11	Sled Equipped With an Airbag run at 30mph.

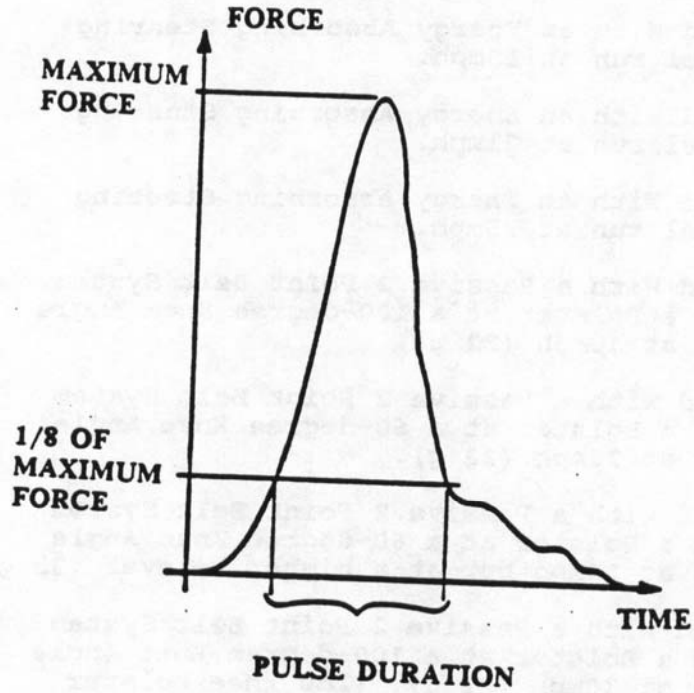
FORCE
MAXIMUM FORCE
1/8 OF MAXIMUM FORCE
TIME
PULSE DURATION

FIGURE 1

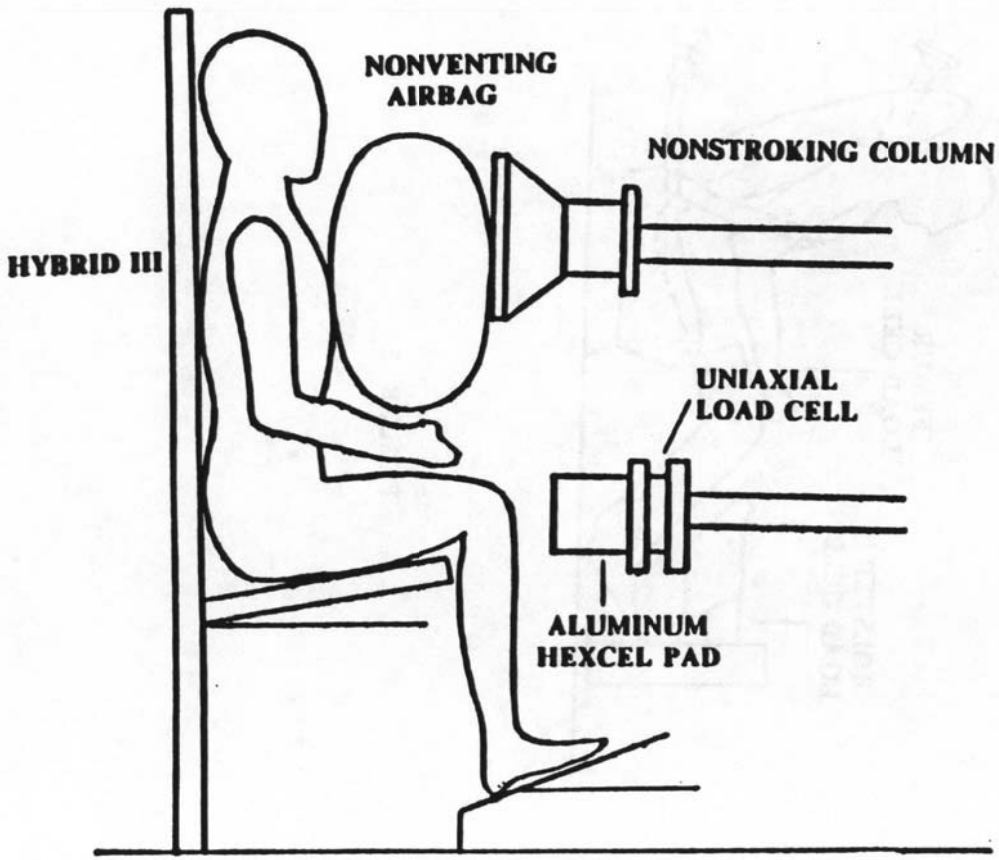
NONVENTING
AIRBAG
NONSTROKING COLUMN
HYBRID III
UNIAXIAL
LOAD CELL
ALUMINUM
HEXCEL PAD

FIGURE 2

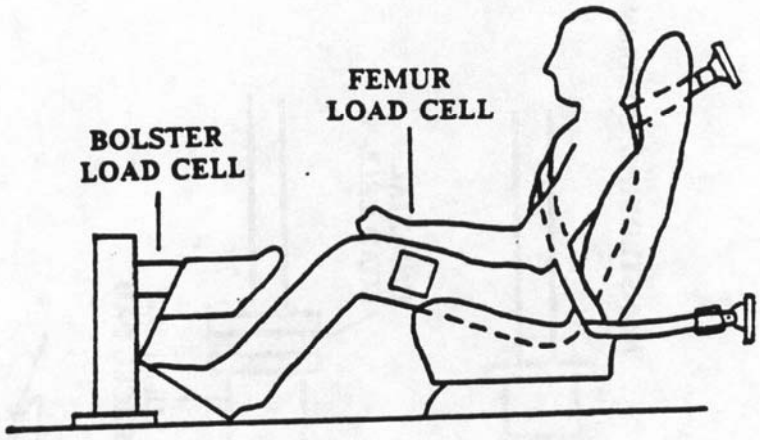

FIGURE 3

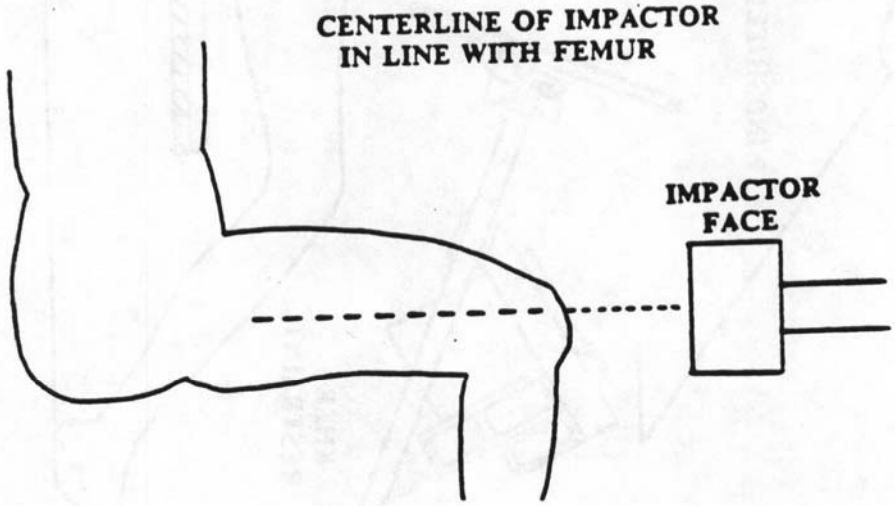

FIGURE 4

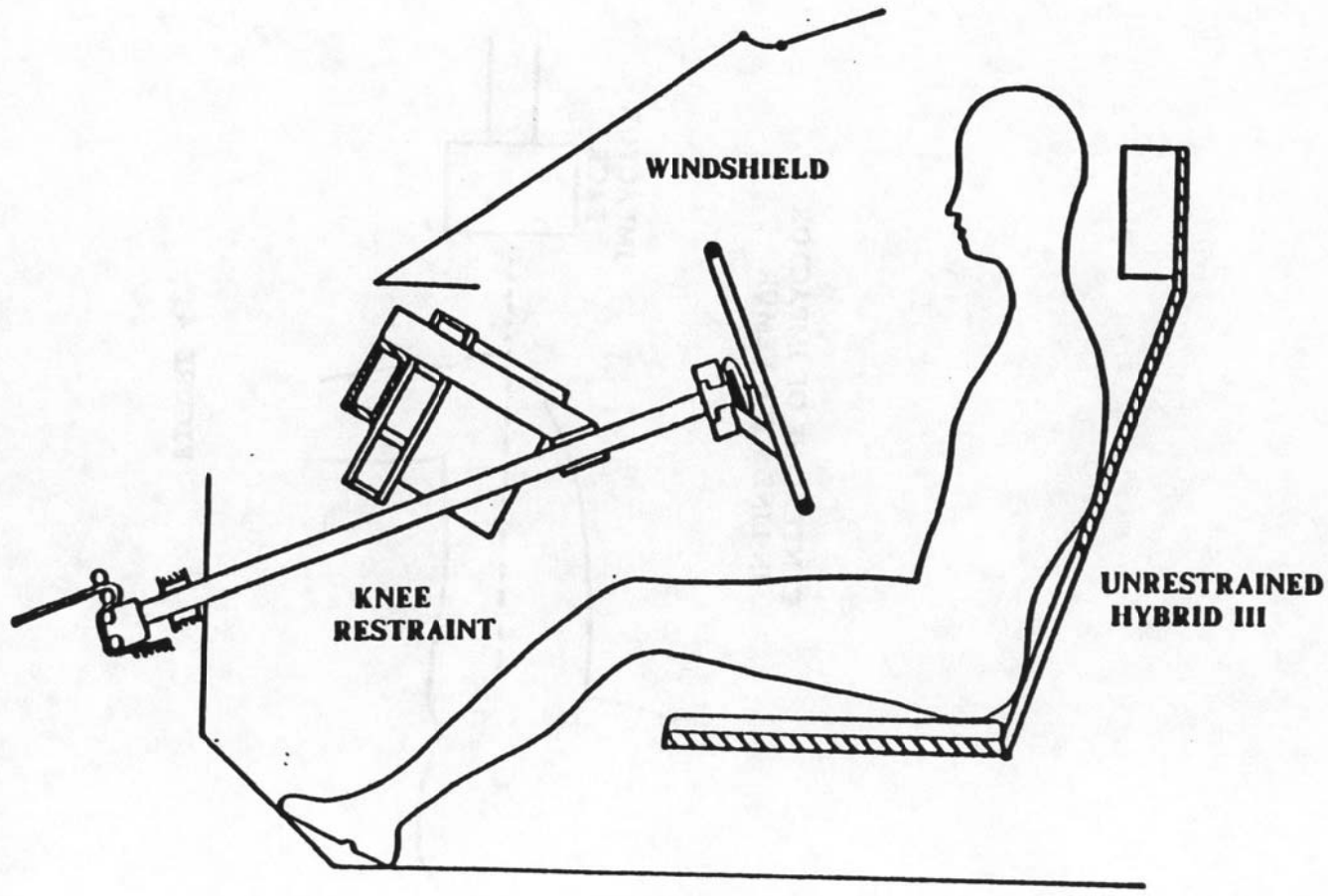

FIGURE 5

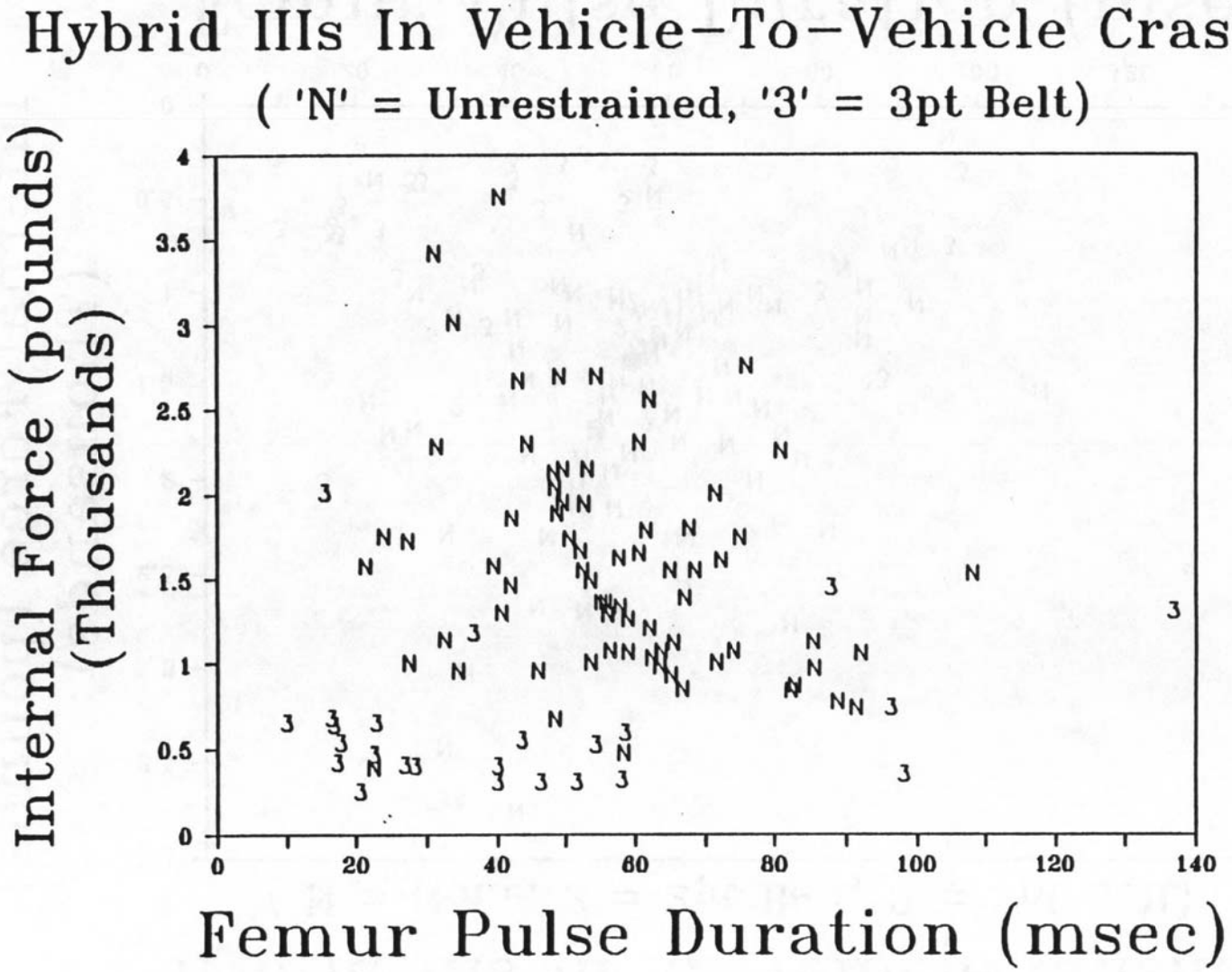
Hybrid IIIs In Vehicle-To-Vehicle Crashes
('N' = Unrestrained, '3' = 3pt Belt)
Internal Force (pounds)
(Thousands)
Femur Pulse Duration (msec)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
20
40
60
80
100
120
140

FIGURE 6

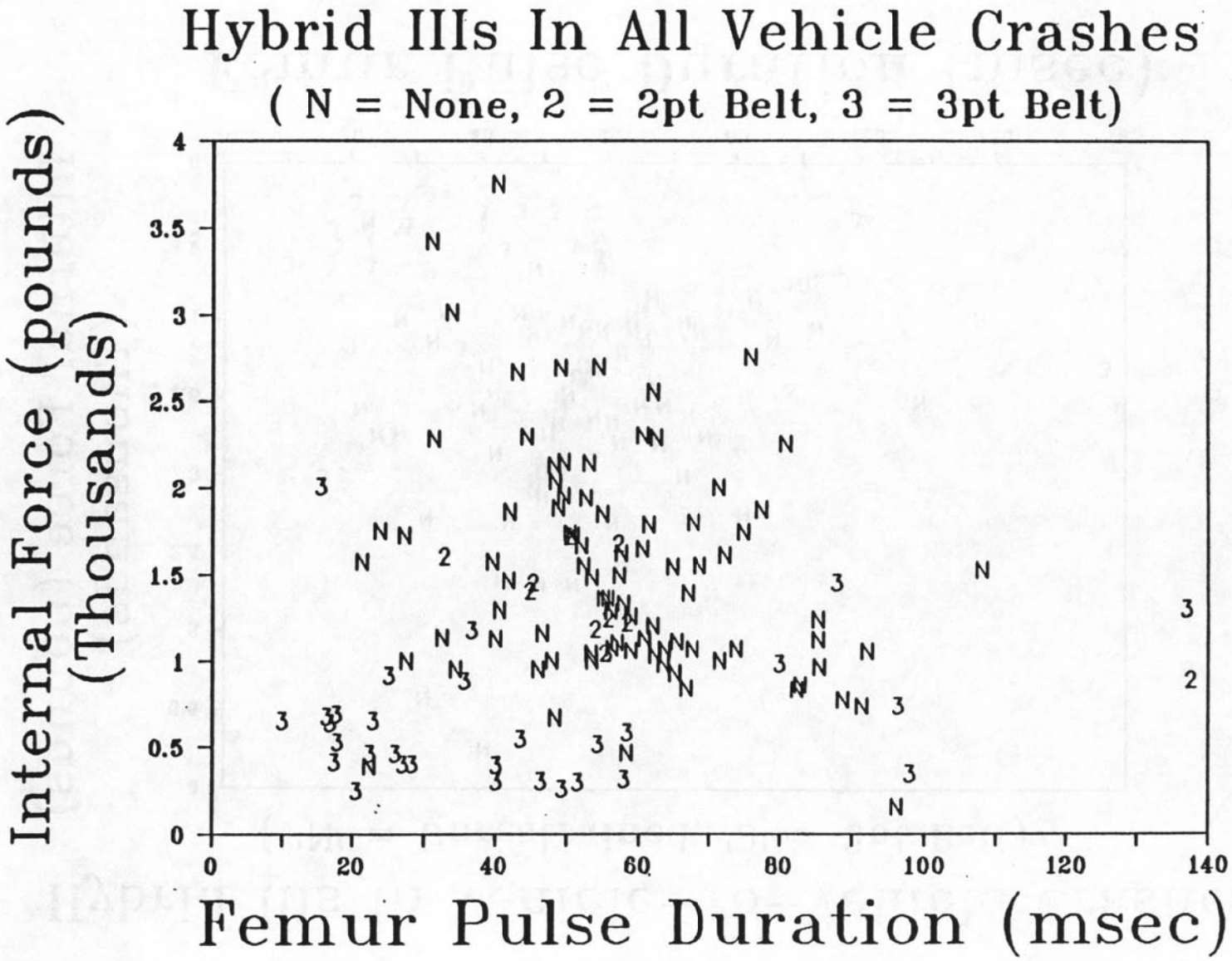
Hybrid IIIs In All Vehicle Crashes
(N = None, 2 = 2pt Belt, 3 = 3pt Belt)
Internal Force (pounds)
(Thousands)
Femur Pulse Duration (msec)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
20
40
60
80
100
120
140

FIGURE 7

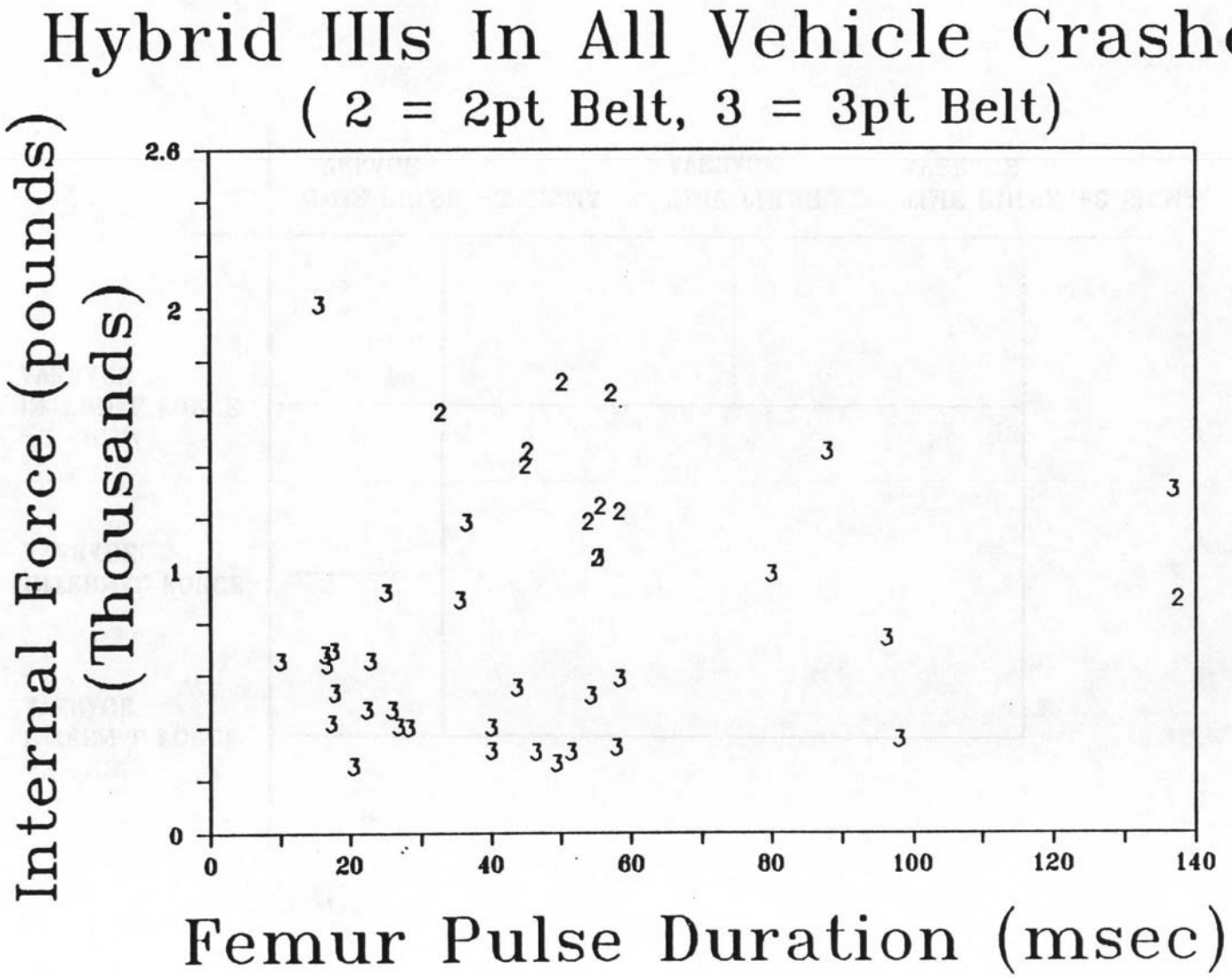
Hybrid IIIs In All Vehicle Crashes
(2 = 2pt Belt, 3 = 3pt Belt)
Internal Force (pounds)
(Thousands)
2.6
2
1
0
0
20
40
60
80
100
120
140
Femur Pulse Duration (msec)

FIGURE 8

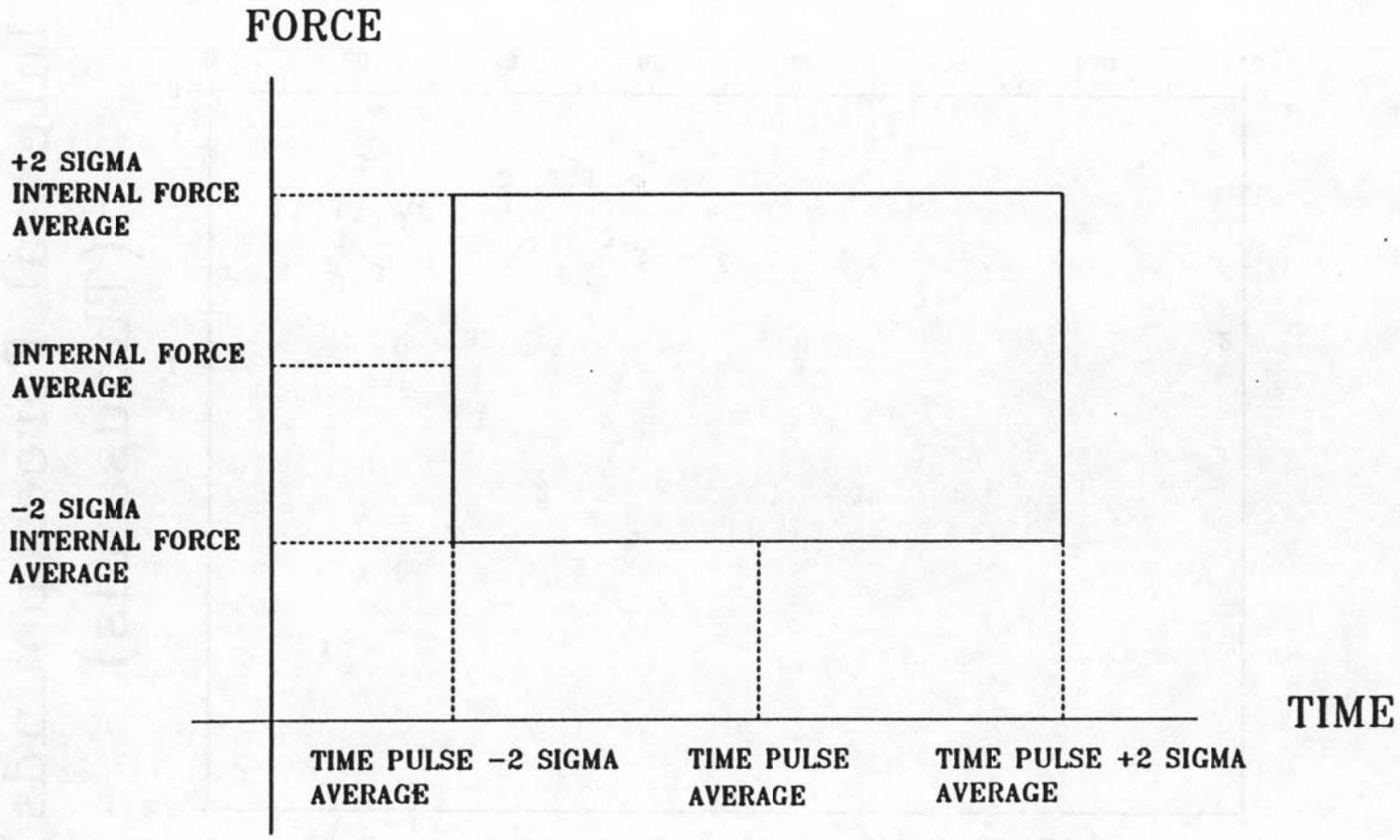
FORCE
+2 SIGMA
INTERNAL FORCE
AVERAGE
INTERNAL FORCE
AVERAGE
-2 SIGMA
INTERNAL FORCE
AVERAGE
TIME
TIME PULSE -2 SIGMA
AVERAGE
TIME PULSE
AVERAGE
TIME PULSE +2 SIGMA
AVERAGE

FIGURE 9

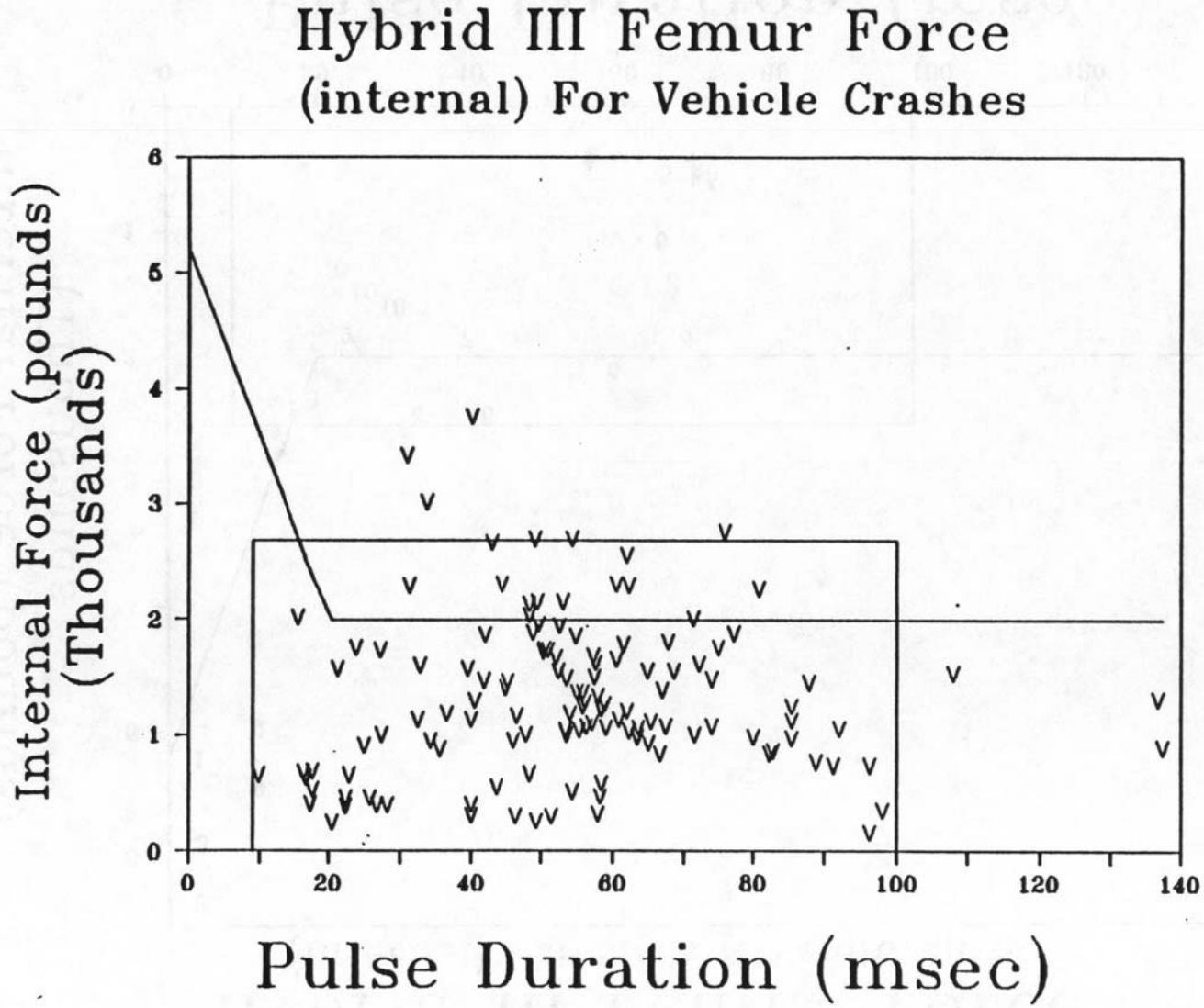
Hybrid III Femur Force
(internal) For Vehicle Crashes
Internal Force (pounds)
(Thousands)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
Pulse Duration (msec)

FIGURE 10

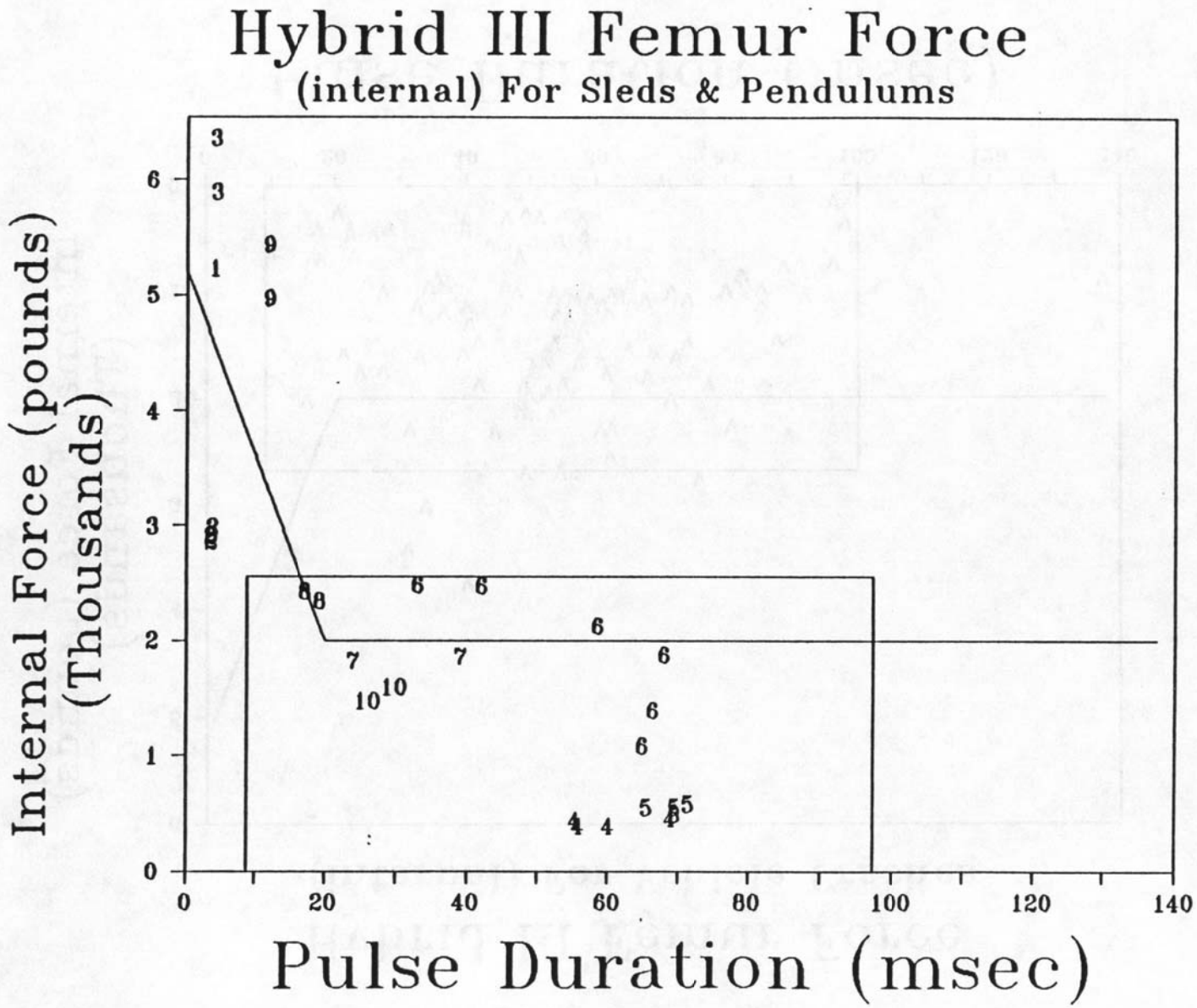
Hybrid III Femur Force
(internal) For Sleds & Pendulums
Internal Force (pounds)
(Thousands)
Pulse Duration (msec)
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140

FIGURE 11

DISCUSSION

PAPER: Hybrid III, Femur Response to Pendulum Sled and Vehicle Impact

SPEAKER: Richard Morgan

Q: Guy Nusholtz, Chrysler

I think we have a different interpretation of what a small amount of padding is. Two inches of styrofoam or some type of padding is an awful lot. Basically, with that much padding it almost transforms the impact response of the dummy to be similar to the impact response of a cadaver. Is it some sort of fluff padding or cotton balls that doesn't interact?

A: Richard Morgan

I looked back at Hering and Patrick who did some work; maybe it was 1978 or 1979. At that time, they used a large amount of padding on the front of the pendulum.

Q: How much is a large amount? Is that like eight inches?

A: Yes. I tried to measure it from the photographs that were there and I would say it was a large amount. When I read the Hering and Patrick paper I think that the dummy was looking very much like the cadaver subjects that were used. You can find great similarities between current dummies and cadavers with a pendulum if you put enough padding on the front of it. The only thing I meant about the padding was; that if it's a rigid or near rigid face on the pendulum, and if you just choose one inch or two inches of padding which is fairly stiff; there will be a transition region at which the padding gets much softer or the padding becomes much thicker and all surrogates will start to look alike because the padding is driving the response.

Q: The only point I am trying to make is that two inches is a lot of padding, it is not like a little bit. You can get a lot of change between rigid and two inches of padding.

A: You are saying you can go out and find a very soft padding that would bring it down quite a bit?

A: That's correct.

Q: Bendjellal, APR

I would like to know whether you measure all of the parameters differently from the uniaxial femoral force as moment acting on the femur?

A: No I did not. I just used the load cell that's in the Hybrid III and that's a uniaxial. I did not use an accelerometer on the pelvis because not all of the data sets had the accelerometer.

I didn't use an external load cell on the instrument panel of the vehicles because I did not have those in the vehicles.

Q: You have only the internal femoral force measurement in all data sources?

A: Yes. It's common to all data sources.

Q: Pat Kaiker, Chrysler, DIE

What type of padding was used and did you use new padding each time?

A: Mike Walsh, CRS Associates

It was an inch thick closed cell padding. We took the padding off General Motors love seat infant carrier.

Q: Mike Walsh

Why 1/8 the maximum?

A: If I used less than 1/8, or if I used 1/9 or 1/10 then the algorithm for the particular data would begin to blow up. That is the algorithm would seek the very last point under several conditions. So, I defined it in terms of the max and the 1/8 seem to be a value at which it was a robust algorithm. If I chose 1/5 or 1/4 that would work too. But 1/8 for our data was the lowest fraction at which the algorithm would work robustly.

Q: I've seen this done at 1/5 and I wondered if that would make it less or better behaved. You're saying 1/8 is about where you got in the blow up time?

A: That's correct. Once we did 1/5 and that would work also.