EVALUATION OF CURRENT PRODUCTION AND PROTOTYPE CHILD RESTRAINT SYSTEMS IN THE USA

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INTRODUCTION

Motor vehicle accidents are the major single cause of death from age 1 to 24 years according to the National Safety Council statistics[1]. Nineteen hundred children ages 0-4 were killed in 1972 in motor vehicle accidents and many more were injured. More than 60 percent of all children killed in motor vehicle accidents in 1972 were motor vehicle passengers (as opposed to pedestrians and cyclists). Many of these deaths and injuries could have been prevented had the children been wearing a proper restraint system.

Research regarding effective child protection has been underway since the 1950's. Moore, et. al.[2] reported the accident experience of children in auto accidents. Dye[3] evaluated a large series of child restraint devices and proposed a set of criteria for evaluation of child restraint systems. Aldman[4] and Appoldt[5] both discussed child restraint systems. In 1968, Siegel[6] related child restraint design to injury protection based on accident cases. He recommended the use of lap belts for children over four years of age and special restraint devices for younger children.

Burdie[7] suggested that the child's braincase is weaker than that of an adult, and pointed to the danger of restraining a small child with an adult lap belt only, since the iliac crest is not fully developed. He also suggested that restraint loads be distributed widely over the chest.

In 1969, King[8] proposed a set of design criteria and suggested that a stable support platform be used in any restraint devices for a child of less than 50 pounds. In 1970, Feles[9] and Heap[10] discussed the development of (respectively) the General Motors Infant Seat and the Ford Tot-Guard. Also in 1970, Robbins, Henke, and Roberts[11] documented the limitations of several then available child restraint devices. Performance criteria and design guidelines were proposed. Subsequently, the first Motor Vehicle Safety Standard for child seating systems (FMVSS 213) was issued by the National Highway Traffic Safety Administration (NHTSA).

In 1972, Roberts[12] reported on the development of new child restraint devices, and developed performance standards and procedures for testing child restraint devices.

A large body of in-depth accident investigation data is found in the Highway Safety Research Institute's MDAI Collision Performance and Injury Report (Revision 3, occupant file) which brings together computerized U.S. accident data from a number of field study sources. This file contains information on 224 children five years old or younger who were passengers in the case vehicles; of these children, only 31 were restrained (by an adult lap belt or by a child seat). No deaths or dangerous injuries occurred among the restrained children. Five of the 12 children restrained by a child seat and 9 of the 19 restrained by an adult lap belt were not injured. Among the 193 children who were not restrained, 3 were killed and 7 others received dangerous injuries.

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Some of the basic approaches to child restraint design taken by manufacturers are shown in Figures 1, 2, 3 and 4. Figure 1 shows the old style pedestal type seat where the child is restrained by an adult lap belt. In this type of seat, the lap belt bears all of the load due to the inertia of the child, plus that of the seat itself. This load is carried entirely by the child's abdomen.

Figure 2 demonstrates the newer type of pedestal seat, where the child is restrained by 4 or 5 point belts which distribute the load over his torso. The seat is restrained by the lap belt, and in a few models, by an additional strap running over the back of the adult seat which fastens to the top of the child seat. This additional strap reduces or eliminates the problem of structural collapse.

A significant performance characteristic of this type of seat is that while it restrains the torso, the head rotates forward and downward which loads the neck.

Figure 3 is an example of the shield or enclosure type of restraint device. In these seats, the load is distributed over a surface molded to conform to the child's body. This type of seat has excellent load distribution qualities, but the child's face and head may strike the semi-rigid shield relatively hard on impact.

Figure 4 uses the same approach for infants but rides him backward distributing the load over the back side of the child.

TEST PROGRAM

The objective of this study is to investigate the protection potential offered by various production and prototype child restraint systems. In order to achieve this it was necessary to:

1. Determine which parameters of child seat performance are relevant to injury prevention.
2. Select a test dummy for use in the study.
3. Construct a test environment, including a dash, floorpan, door and automobile seat capable of being oriented for front, back and lateral impacts.
4. Select instrumentation and data-handling procedures to determine accelerations and occupant motions for performance evaluations.
5. Select a test matrix.

Performance Criterion - Injury to the child in a restraint system during impact can arise from three basic causes. First, and probably most critical, is the possibility of the child being thrown on impact against the interior of the vehicle. Second is excessively high head and chest acceleration. The third is stress to vital organs due to improper load distribution.

Real life automobile crashes vary widely in direction and velocity of impact, vehicle interior, vehicle structural integrity, and passenger seating arrangement. Multiple impacts and rebound also play important roles in automobile crashes.

In all accident configurations and especially in side impacts, there is a possibility of significant reduction in passenger compartment dimensions (intrusion) especially along the axis of impact. In a side impact the door or vehicle side wall may be pushed inward reducing the space available for head excursion or even pushing the side into the restraint system. A child safety restraint system must provide significant protection for all likely combinations of these variables. A necessary (but not sufficient) condition for injury protection is that the restraint system prevent the child's head from striking the vehicle interior. The single most important measure of the injury protection afforded by a restraint system, therefore, is the extent to which it limits head excursion in all directions.

The role of head acceleration in brain injury is not well understood. No causal relationship has been established between head acceleration per se and brain injury. Only when the acceleration results from an impact with solid structures has there been suitable injury criteria developed.

Since it is difficult to obtain a good force-time curve in an automobile crash, head acceleration has traditionally been the input parameter upon which many injury prediction formulas are based[13]. The Gadd Severity Index (SI), the Head Injury Criterion (HIC), and the Maximum Strain Criterion (MSC), among others, use the head-acceleration-time recorded to estimate the severity of head injury which is likely to have resulted to an adult human occupant in a crash.

All head acceleration criteria are based upon the adult, and only qualitative statements can be made about the analogous criteria for infants and small children. In comparison to an adult the child's head is larger, the neck is weaker, and the skull is more pliable. All of these factors indicate that a child's tolerance to head impact is likely to be somewhat less than that of an adult's.

Chest acceleration has been the most important parameter in injury prediction for the thorax for the last 25 years. The adult chest is stiff and acceleration may be a fair parameter for injury prediction. The bone structure of a child's sternum and rib cage is not nearly as rigid as in the adult. In addition, his heart is relatively larger. These factors indicate that a child may be more susceptible to thoracic injury than an adult, and that chest deflection rather than chest acceleration may be a better indication of injury.

The third cause of injury to a child in a restraint system during impact is stress to vital organs due to improper load distribution. The location of the restraining (load bearing) surfaces is especially critical in children because some skeletal regions are not fully developed, and ossification is not complete. In particular, the iliac crest has not developed and therefore doesn't provide as good a load bearing structure for a child as for an adult. Thus, a single lap belt has a strong tendency to ride-up over the pelvis and into the abdominal region with dangerous consequences.

An important and dangerous effect which is not reflected in quantitative data is submarining: the child slides down out of his protective restraints into a position where the restraint belts bear down upon the lower abdomen in a potentially injurious fashion.

Selection of Occupant - The 3-year-size Sierra Engineering anthropometric dummy was used for all tests (Figure 5), except the infant carrier tests. The Sierra 3-year is 37.5 inches (95.3 cm) high and weighs 32 pounds (142.4 N). The weights of various body components are distributed nearly completely thus giving a fair duplication of body kinematics.

The Sierra 3-year has some important performance characteristics which must be considered when evaluating experimental results. Most notable of these characteristics are its steel clavicle and hard rubber neck which does not accurately simulate human response in a crash environment. These responses are particularly important in evaluating a 5-point harness system.

In order to test the infant restraints, a doll with the approximate dimensions of an average six-month-old baby was disassembled. The two legs, torso, two arms, and head were weighted with lead shot to simulate the body segment weights for a baby of this size. The doll was then reassembled. The length of the doll was 16 inches (40.6 cm) and it weighed 15 pounds (66.8 N). This technique has also been used by others in developing their infant carriers (Figure 6).

Test Environment - The test configuration consisted of an unsupported General Motors bench seat mounted on a test rig which duplicated the seat mounting (center position), dash, side door, lap belt attachment points, floor and toe board locations in a full size 4 door 1973 General Motors vehicle. The entire assembly was capable of being rotated as a unit and thus the geometry of the simulated vehicle remains constant for front, side, and rear impacts.

Instrumentation and Data Handling Procedures - The 3-year dummy was instrumented with triaxial accelerometer packs in the head and in the chest. The individual accelerometers were Setra Model Number 111. A Statham strain-gage accelerometer was used to sense sled deceleration. Timing signals and impact velocity were also recorded using a Honeywell 1612 light-beam oscillograph.

High-speed motion pictures were also taken for each test. A Photosonics 16-mm camera was located directly to the side of the impact area, and another directly overhead. The filming rate used was 1000 frames per second. These motion pictures were supplemented by slides taken before and after each test. Also, a Graph-Chek sequence camera was used in the test program to provide an instantaneous evaluation of the test as a sequence of eight frames on a 3 x 5 in. Polaroid sheet.

Test Matrix - The test matrix for this program was designed to include forward impact, side impact, and rear impact. Each of the restraint devices was mounted on the bench seat in accordance with the manufacturer's instructions, securing the dummy in the device with the appropriate emergency restraints. All of the test devices were tested in the frontal impact direction at 30 mph (48.3 kph) and 21 G's. The devices which performed satisfactorily (did not hit the dash) were then tested, with new restraints where necessary, in the side direction at 20 mph (32.2 kph) and 16 G's. Those devices which performed satisfactorily in the side impact were then tested for rear impact performance at 20 mph (32.2 kph) and 16 G's. A description of each device tested is given in Table I.

RESULTS

The data from all tests are summarized in Table II. All acceleration and head excursion data are given as peak values. All head and chest acceleration values are given in terms of the anterior-posterior (A-P), superior-inferior (S-I) and Left-Right directions.

Two head excursions are used to describe the head motions. The Maximum Absolute Head Excursion (MAHE) is the total head excursion measured at the leading edge of the dummy's head. The Maximum Relative Head Excursion (MRHE) is the forwardmost excursion of the head relative to the vehicle seat. The National Highway Traffic Safety Administration proposed revised performance requirements to Motor Vehicle Safety Standards No. 517.213 limits the forward MRHE to 18 inches (45.7 cm) relative to the forward most point of the vehicle seat back. The vertical MRHE is limited to 27 inches (68.6 cm) relative to the highest point of the unloaded vehicle seat cushion. Side excursion is limited to a MAHE of 19 inches (48.3 cm). The frontal impact head excursion results for the child seats and harnesses are given in Figure 7. The curve represents a comparison of the horizontal MRHE for all the restraints tested.

All of the seats tested for side impact except the GM Love Seat, Century 4301 and the Peterson 75 impacted the car door, when tested in the outboard position. The maximum MAHE to clear the door was 12 inches (30.4 cm).

All rear impacts were very smooth with low head and chest acceleration and no seat structural damage.

Load Distribution - The General Motors (GM) Love Seat, Kantwet 784, International 8700 and 8900, Bunny Bear QN90X, Century 4301 and Peterson 75 (child system) all employ similar belt systems. They position the child restraint lap belt over the child's pelvis, thus avoiding the excessive abdominal loads which result when the lap belt is too high. Each seat uses a pair of shoulder harnesses which limit excursion of the head and torso. All systems use a "crotch strap" to reduce submarining.

The Love Seat and the Century 4301 give effective direct side impact protection because of wings which retard head motion. The Peterson 75 (child system) gives effective side protection by the use of a side strap which prevents the seat from large side movements. The Kantwet 784, International's Models 8900 and 8700, and Bunny Bear QN90X all allowed contact with the door but the harness had slowed the head velocity substantially or the seat padded side walls offered some protection.

The Ford Tot-Guard, Chrysler Mopar, Bobby-Mac and Peterson 75 (toddler system) seats employ the same type of load bearing surface. All have semi-rigid encasing shells that bear upon the child's chest and abdomen in a front impact. The impact loads are very well distributed in front impacts. The dummy's face contacted the shield of the Bobby-Mac.

The Ford Tot-Guard, Chrysler Mopar, and Bobby-Mac all give limited direct side impact protection. The Peterson 75 (toddler system) gives good side protection by the use of the side strap.

The Sears harness distributed chest impact loads fairly well, but allowed large forward head excursions. In the side impact test little protection was given. The Infanseat Harness uses the same five-point belt system used in the Kantwet 784 seat. This system's performance is very similar to the Kantwet 784 seat.

The Irvin I-165 and the Peterson 67B both used the adult lap belt around the child. As a result these two seats offer limited protection in 30 mph (48.3 kph) front impact. Both restraints allowed the dummy's head to impact the simulated dash. No side tests were run.

The GM Infant carrier, Bobby-Mac and Peterson (infant system) all are rearward facing restraints. The impact loads are distributed over the back side of the infant. All these restraints performed very well in front 30 mph (48 kph) impacts. The GM Infant Carrier worked well in side impacts. The Peterson 75 (infant system) worked very well for side impacts because of the side strap used with all Peterson 75 devices. The Bobby-Mac Infant system was not tested with the 6 month doll, but works well in side tests with a 2 month doll.

CONCLUSIONS

Head excursion alone is not enough to assure that the child's head does not strike the dash or seat back. The initial head position must be taken into account for total protection. Both the Ford Tot-Guard and the Peterson 75 (Toddler system) missed the dash by about 5 inches (12.4 cm). The Tot-Guard had 22.6 inches (57.50 cm) of head excursion while the Peterson had only 19.0 inches (48.4 cm) excursion. This difference is due to the initial head position of each seat. The fixed distance as proposed by NHTSA appears to be the most realistic criterion for head excursion evaluation.

All seats evaluated in this study must be installed and used according to their directions. In addition, it is recommended that they be installed in the middle section of the rear seat, wherever possible.

The GM Love Seat, Century 4301, International's models 8700 and 8900, both the Kantwet seat and harness, and the Sears harness require a back strap. When any of these seats are installed in the front seat the strap passes through the rear passenger compartment where it can be an inconvenience. The Peterson 75 requires the side strap for side protection. Without these straps, the protection afforded by these seats is greatly reduced.

The test configuration employed in the side impacts for this study represents the most severe conditions which may result from a real automobile side collision. The child restraint system was installed on a bench seat nearest the point of impact. If the restraint system had been installed in the middle of the seat, or on the side opposite the impact site, the test results would have indicated much less severe consequences.

One additional important limitation upon the performance of all the restraint devices tested was the vehicle seat. The vehicle seat deformed considerably in all tests. Head excursion in the rear impacts, and to a lesser extent in the front impacts was due in part to deflection of the adult car seat back. This deflection allowed the child restraint system to travel further than it would have, had the seat back been more rigid.

ACKNOWLEDGMENT

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Figure 1. Lap Belt Loading Upon Child

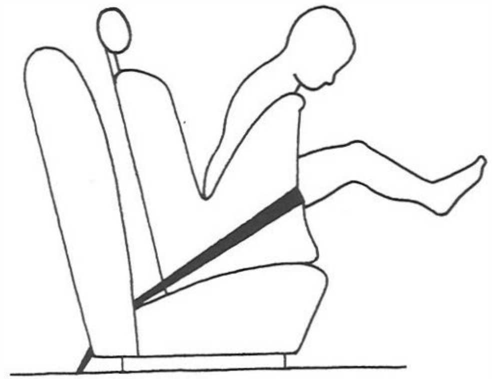

Figure 3. Barrier System with Belt Loading on Barrier

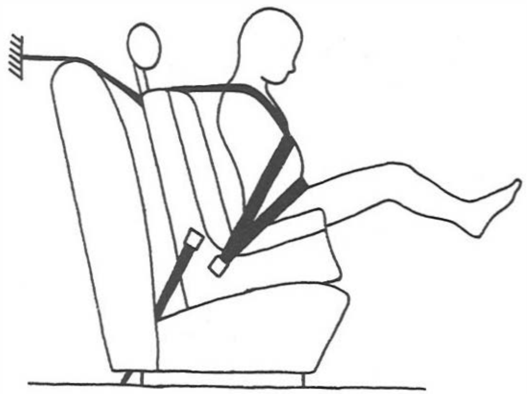

Figure 2. Five-Point Belt System with Lap Belt Loading on Seat

Figure 4. Infant Restraint System

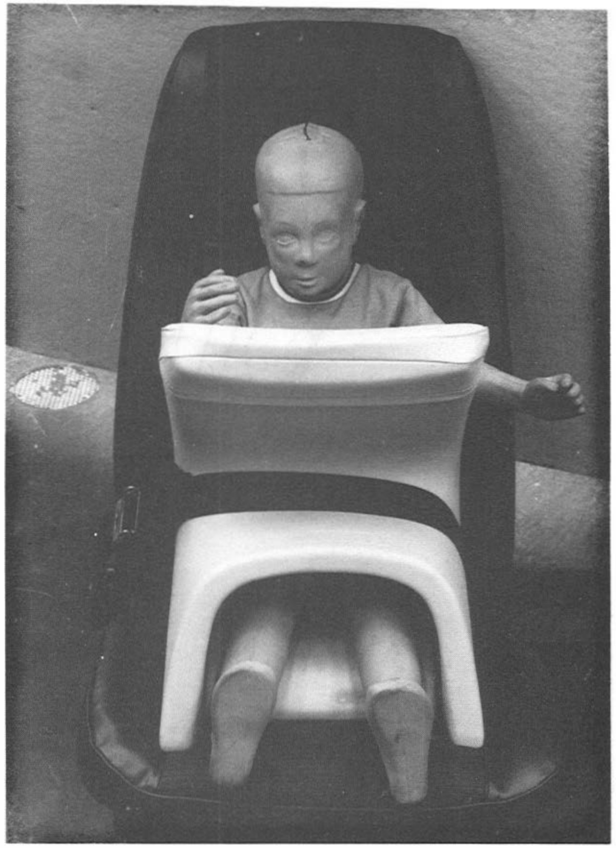

Figure 5. Sierra 3-year Anthropometric Dummy

Figure 6. Weighted Doll

TABLE I DEVICES SELECTED FOR TESTING

MANUFACTURER	SEAT NAME	DESCRIPTION
Peterson Baby Products 6904 Tujunga N. Hollywood, Ca. 91605	Imperial Safe-T-Seat Model 67B	Tubular fold-up pedestal. Padded seat and face shield. Child lap and crotch belts. Child seat restrained by adult lap belt.
	Model 75 Infant System	Molded plastic shell with padding. Child rests in a semi-reclining position rearward facing. Shoulder straps. Side restraint strap to limit side motion.
	Model 75 Toddler System	Molded plastic seat with padding. Molded and padded plastic shield. Encapsulating trunk region. Crotch strap, and side restraint strap, seat and shield restrained by adult lap belt. Back strap and pedestal provided.
	Model 75 Child System	Molded plastic seat with padding. Suspender type child shoulder harness, lap and crotch belts. Child seat restrained by adult lap belt. Side restraint strap for side motions.
Ford Motor Co. c/o American Road Dearborn, Michigan	Tot Guard	Molded Plastic shell encapsulating child. Child sits on molded plastic riser within shell. Adult lap belt restrains shell. Padded face guard.
Chrysler Corporation Parts Division Detroit, Michigan	Mopar Seat Part No. 3744976	One piece molded plastic seat-shell combination restrained by adult lap belt. Padded face guard. Child slips into shell from top.
General Motors Corp. P.O. Box 7096 North End Station Detroit, Michigan 48202	Love Seat	Molded plastic seat with padding. Side support along entire upper torso. Lap, crotch and suspender straps with one universal buckle. Retained by adult lap belt and top belt over carseat attached to rear seat belt.
	Infant Carrier	Molded plastic shell, occupant rests in a semi-reclining position rearward facing. Shoulder straps.
Collier-Keyworth Co. Gardner, Mass. 01440	Bobby-Mac Child System	Molded plastic seat with padding. Molded and padded plastic shield encapsulating trunk region. Double diagonal chest harness with belly strap. Seat and shield restrained by adult lap belt.
	Bobby Mac Infant System	Molded plastic shell. Occupant rests in a semi-reclining position rearward facing. Shoulder and belly straps.
Irvin Industries, Inc. 1315 Versailles Rd. Lexington, Ky. 40501	Child Car Seat and Safety Cushion Model I-165	U-shaped vinyl and cloth "bean bag" (styrofoam beans) for face protection. Plastic seat riser with pad. Bag and seat riser restrained by adult lap belt.
Kantwet Baby Products 501 Young Street Piqua, Ohio	Fitz-All Deluxe Recliner Model 784	Tubular fold-up pedestal. Padded seat and chest guard bar. Suspender type child shoulder harness, lap and crotch belt. Child seat restrained by adult lap belt and top strap over car seat anchor to floor.

TABLE I DEVICES SELECTED FOR TESTING (continued)

MANUFACTURER	SEAT NAME	DESCRIPTION
Kantwet Baby Products (continued)	Infanseat Harness Model 275	Suspender, waist, and crotch straps. One universal buckle. Anchor strap around car seat back and anchored to floor.
Sears, Roebuck, and Co. Chicago, Ill. 60607	Harness #6401 Part No. 504082	Small harness size with vest, crotch and shoulder straps. Anchor strap encircles car seat back.
Century Products, Inc. 2150 W. 1145h St. Cleveland, Ohio 44102	Century Model 4301	Molded plastic seat with padding. Side support along entire upper torso. Lap, crotch, and suspender straps with one universal buckle. Retained by adult lap belt and top belt over car seat attaches to rear seat belt.
Bunny Bear, Inc. Nursery Lane Everett, Mass. 02149	Model QN90X	Tubular seat with side support. Five point harness. Prototype seat.
International Manufacturing Co. 2500 Washington St. Roxbury, Mass. 02119	Teddy-Tot Model 8900	Tubular fold-up pedestal. Padded seat and chest guard bar. Suspender type child shoulder harness, lap and crotch belt. Child seat restrained by adult lap belt and top strap over car seat anchor to floor. Prototype seat.
	Teddy-Tot Model 8700	Same as above. Reclinable, prototype seat.

TABLE II CHILD SEAT FRONTAL IMPACT TEST SUMMARY

Manufacturer And Model	Head Acceleration			Chest Acceleration			MAHE		MRHE		Comments
	A-P G's	L-R G's	S-I G's	A-P G's	L-R G's	S-I G's	in	cm	in	cm	
Bunny-Bear QN90X	60	15	90	35	5	20	21.4	54.4	22.9	58.2	Prototype seat
Chrysler Mopar	102	15	35	41	22	31	19.9	50.5	19.1	48.5	Production seat
Century 4301	74	15	80	35	2	LOD	16.8	42.7	18.0	45.7	Production seat
Collier-Keyworth Bobby-Mac	21	83	10	37	10	19	17.0	43.2	20.1	51.1	Production seat
Ford Tot-Guard	67	10	38	35	12	18	22.6	57.4	20.9	53.1	Production seat
General Motors Love Seat	65 50 55	11 10 35	66 70 63	35 32 37	5 11 6	21 16 22	18.5 24.9 16.6	47.0 63.3 42.2	17.6 25.6 17.5	44.7 65.0 44.5	Production seat Tested without the back strap* Tested with the adult lap belt around the lower base*
Irvin I-165	230	50	44	40	8	33	22.9	58.2	26.0	66.0	Production seat
International Manufacturer Model 8900 Model 8700 Model 8700	95 90 105	10 10 5	45 40 50	32 30 35	2 5 7	30 25 33	15.8 13.5 16.0	40.1 34.3 40.6	14.3 14.5 15.2	36.3 36.8 38.6	All are prototype seats. Tested in up-right position Tested in reclined position
Kantwet 784	48	8	46	29	9	18	18.0	45.7	18.8	47.8	Production seat
Peterson 67B	220	34	78	78	38	15	23.7	60.2	26.0	66.0	Production seat
Peterson 75	65	14	74	38	7	5	19.0	48.3	21.0	53.3	Toddler system (shield) without the back strap
Peterson 75	40	7	68	34	7	16	19.3	49.0	21.8	55.4	Child system (harness) without the back strap
Peterson 75	85	5	60	30	10	15	16.6	42.2	14.6	37.1	Child system (harness with the back strap
Kantwet Infanseat	35	8	50	30	6	15	16.9	42.9	19.4	49.3	Production harness
Sears #6401	52	6	77	34	18	15	21.1	53.6	25.5	64.8	Production harness
Sears #6401	223	30	70	45	20	16	24.0	61.0	26.0	66.0	Harness*

LOD - Loss of Data
* - Restraint Installation not in accordance with manufacturer's recommendation

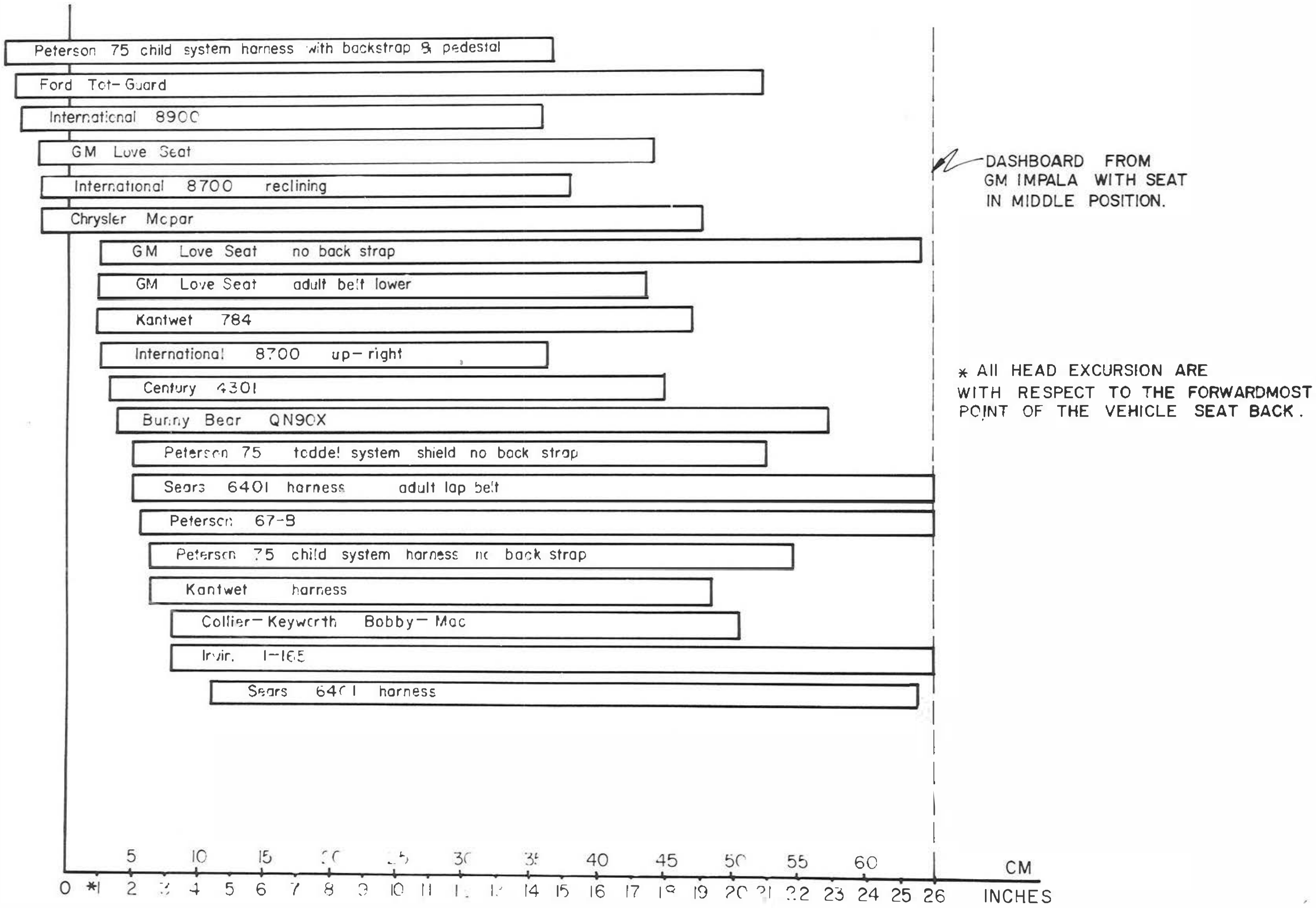

Figure 7. Head Excursion for Frontal Impacts