Department of Veterans Affairs

Journal of Rehabilitation Research and Development Vol 33 No. 3, July 1996
Pages 279–289

Shoulder belt anchor location influences on wheelchair occupant crash protection

Gina Bertocci, PE, MSME; Kennerly Digges, PhD; Douglas Hobson, PhD
University of Pittsburgh, Rehabilitation Technology Program, Pittsburgh, PA 15238

Abstract—An investigation of the effect of the shoulder belt's upper anchor point location on crash protection during wheelchair transportation was conducted using a lumped parameter crash victim simulator. While varying the upper anchor point location in each of three directions, the occupant kinematics and injury criteria of the Hybrid III test dummy were determined. Through comparison of these parameters and their associated trends, it was determined that varying the location of the anchor point has a significant effect on the crash protection of the occupant.

Key words: *occupant crash protection, occupant restraint anchorages, wheelchair transportation safety.*

INTRODUCTION

Research and development in the area of transportation safety has had a long and successful history. Perhaps one of the most effective safety measures introduced to the industry is the safety belt, or occupant restraint, which alone is estimated to save 5,000 lives each year[1]. The design and implementation of this and other safety devices in the automotive transportation environment are guided by the Federal Motor Vehicle Safety Standards (FMVSS) as developed by the National Highway Transportation Safety Administration (NHTSA). FMVSS 210, along with several Notices of Proposed Rulemaking (NPRM) to this legislation, specifically addresses occupant crash protection systems (1). Details such as occupant comfort while wearing safety belts and recommended anchorage points are addressed in these documents. While attempting to maintain optimum crash protection, comfort has been one of the primary focuses of recent NPRMs, since increased occupant comfort is believed to lead to a greater tendency to use safety belts.

Unfortunately for individuals with disabilities, the parameters set forth in these documents were developed primarily with the intent of application to nondisabled drivers and passengers. Individuals who cannot transfer and must use their wheelchair as a seat during transportation have not realized the abundant benefits of the research and development that has taken place in this industry. In fact, direct application of FMVSS guidelines to public wheelchair transportation may be impractical in some cases. The prescribed upper anchor point of the shoulder belt, for instance, presents difficulties, as physical limitations are imposed by both the wheelchair and the interior structure of the vehicle. To investigate the effect upper anchor point limitations have upon the crash protection of the wheelchair occupant, an analysis employing computer simulations of various anchoring scenarios was conducted.

METHODS

An occupant simulation software system, Dynaman (Gesac, Inc., Kearneysville, WV 25430), modeling the International Standards Organization's (ISO) Standard 10542 surrogate wheelchair secured by a four point

This material is based upon work supported by National Institutes on Disability and Rehabilitation Research, Rehabilitation Engineering Research Center on Technology to Improve Wheelchair Mobility.

Address all correspondence and requests for reprints to: Gina E. Bertocci, University of Pittsburgh, Rehabilitation Technology Program, UPARC 915 William Pitt Way, Pittsburgh, PA 15238; email: ginaber@pitt.edu.

[1]Digges K., University of Pittsburgh, Rehabilitation Engineering Course Notes. October, 1994.

Journal of Rehabilitation Research and Development Vol. 33 No. 3 1996

tiedown system (2), with a Hybrid III anthropometric test dummy restrained by shoulder and lap belts, was used to evaluate the effects of varying the position of the upper anchor point of the occupant restraint. The surrogate wheelchair is a structurally enhanced wheelchair; it and the associated Dynaman model were developed by the Society of Automotive Engineers (SAE) and the ISO Wheelchair Tiedowns and Occupant Restraints Standards committees for repeated testing of wheelchair securement systems without the requirement of continual wheelchair replacement. The model, using a deceleration pulse which simulates a 30 mph, 20 g frontal impact, has been validated through a series of sled impact tests conducted during the ISO and SAE standards development process (3).

For the purposes of this study, the coordinate system and reference points are as shown by **Figures 1** and **2.** The coordinate system locates the origin at the center of the rear edge of the sled/floorboard. The positive x direction is assigned as forward, while the positive y and z directions are established to the occupant's right and downward, respectively.

The validated ISO/SAE model sets the upper anchor point of the occupant restraint, at x=22.65 in, y=−9.9 in and z=−48 in (57.5 cm, −25.1 cm, and −121.9 cm). However, in an actual vehicle, it is reasonable to find the upper anchor point located on the sidewall or ceiling. Hence, it is impractical in many vehicles to simulate a crash with y=−9.9 in (−25.1 cm), since commonly adult wheelchairs have a width of approximately 24 in (61 cm). Therefore, for these simulations the position of the upper anchor point of the shoulder belt was derived from both, by applying FMVSS defined belt comfort zones to a wheelchair occupant, as well as physical and structural constraints found in the vehicle which impose limitations on the location of the upper anchor (4,5).

Considering these factors, a baseline case was developed from which other simulation runs were conducted by varying only one parameter at a time. Accordingly, the anchor coordinates shown in **Figures 3** and **4** were utilized in conducting the study. The baseline case in the frontal (yz) plane, fixes the y coordinate equal to −24 in (−61 cm), allowing for half the typical wheelchair seat width of 24 in (61 cm), in addition to 4 in (10.2 cm) for wheel width, plus a clearance between the wheelchair and vehicle wall of 8 in (20.3 cm). The z coordinate was chosen by transforming the FMVSS's recommended shoulder belt comfort zone shown in **Figure 5** to the 50th percentile male wheelchair user. The center of this zone yields a 55° angle between the sternum reference horizontal plane and the shoulder belt. This angle, in conjunction

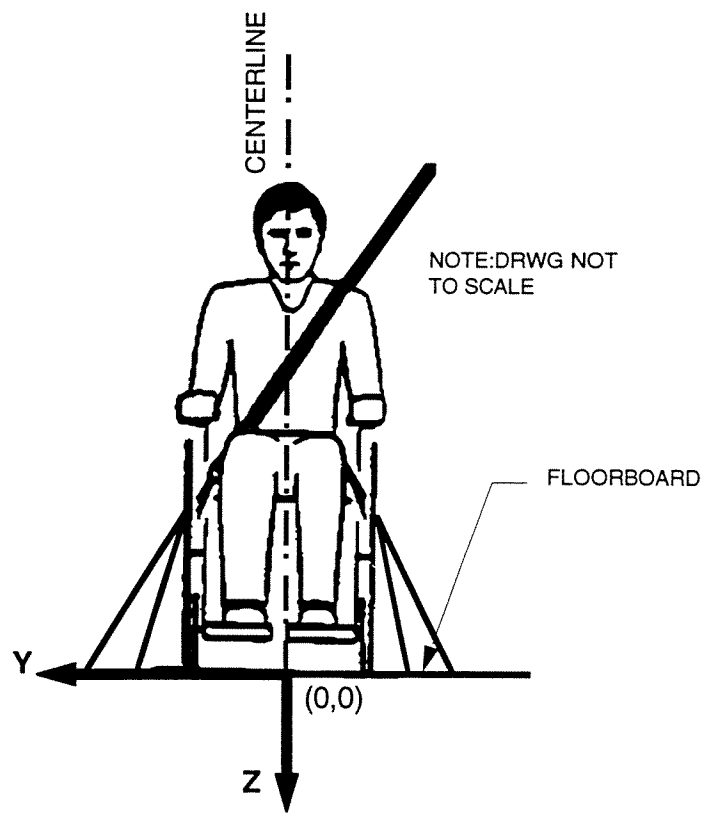

Figure 1.
Coordinate system and origin transverse (frontal) plane.

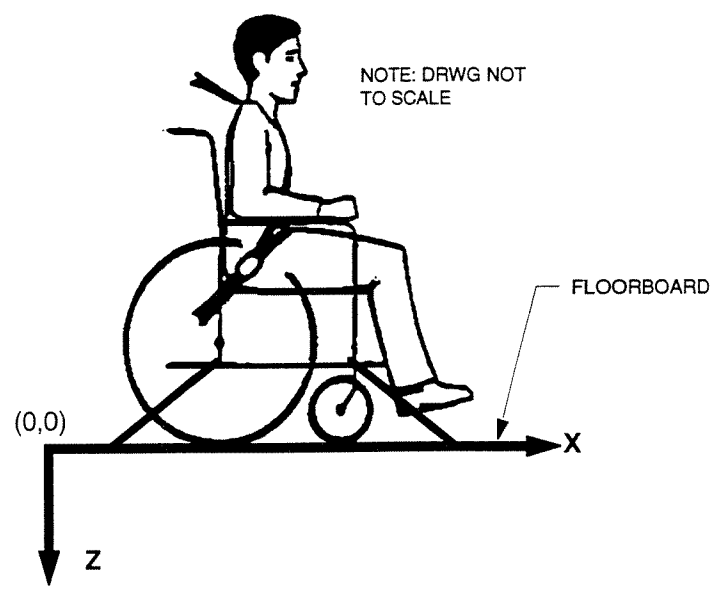

Figure 2.
Coordinate system and origin longitudinal (sagittal) plane.

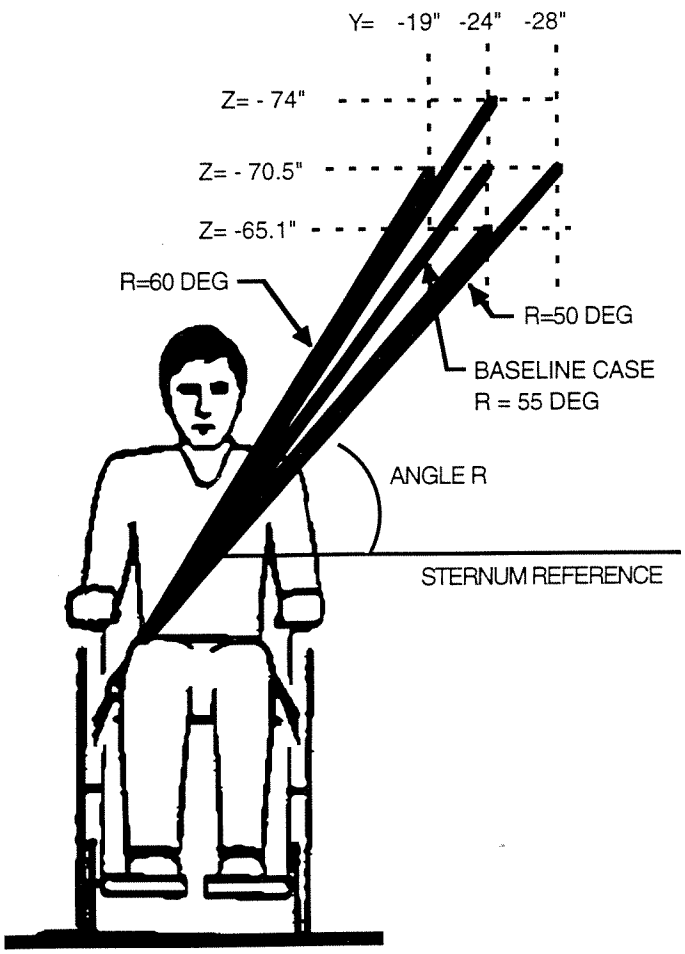

Figure 3.
Variations in upper anchor point transverse (frontal) plane.

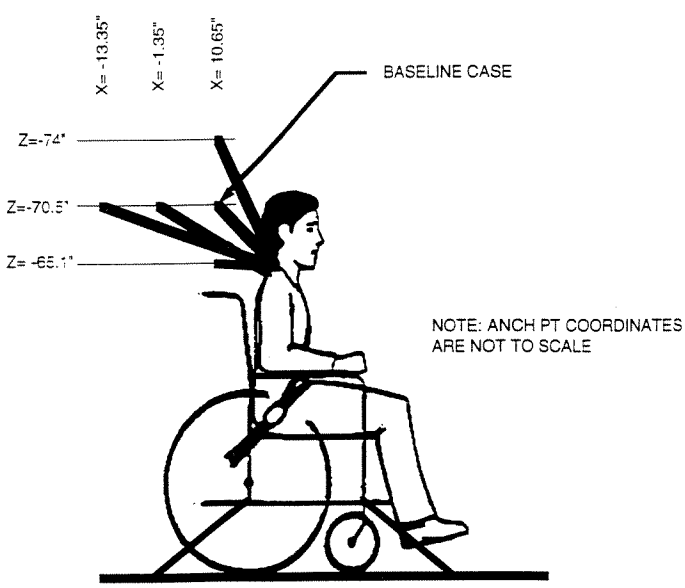

Figure 4.
Variations in upper anchor point longitudinal plane.

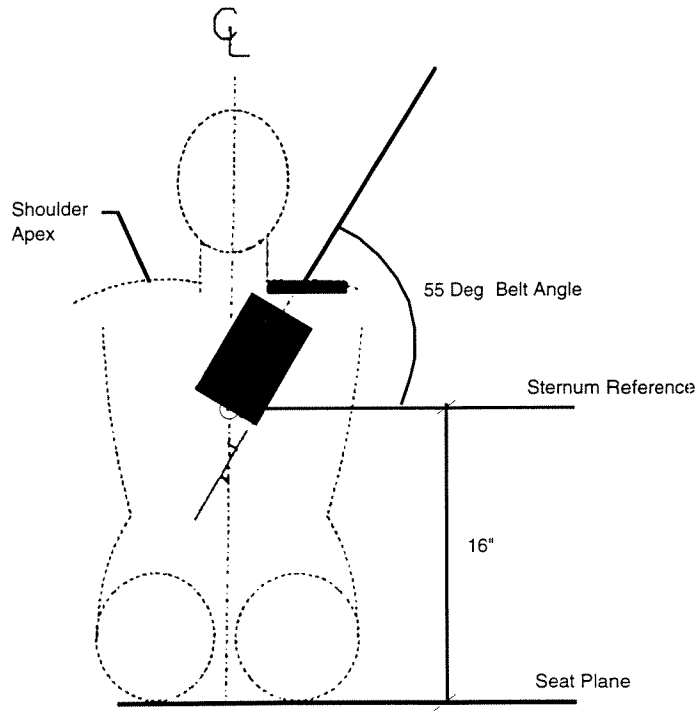

Figure 5.
FMVSS recommended shoulder belt comfort zone: 50th percentile male.

with the previously defined y-coordinate point, leads to a z-coordinate value of −70.5 in (−179.1 cm). In the longitudinal plane, as shown by **Figure 4,** the baseline upper anchor point has been assigned an x-coordinate value of 10.65 in (27.05 cm), placing it approximately 12 in (30.5 cm) aft of the apex of the shoulder. This x coordinate was selected as a starting point based upon physical limitations of vehicles, as well as that typically found for a nondisabled passenger in a private vehicle. The lower anchor point of the shoulder belt was located on the vehicle floor, at x=16.9 in and y=10.4 in (42.9 and 26.4 cm), which are the same coordinates utilized in the ISO/SAE validated model. This anchor point seemed reasonable when considering vehicle constraints and was maintained throughout this study.

To systematically determine the effect of altering the location of the upper anchor, a number of simulations were run while varying its position along only one axis while holding the other two coordinates constant. This process was followed for each of the three coordinate axes. For each simulation, data regarding the linear and angular accelerations and the linear displacements of the head were collected over a 240-msec period. Acceleration profiles of the head and upper torso were further used to derive the Head Severity Index

Journal of Rehabilitation Research and Development Vol. 33 No. 3 1996

(HSI), Head Injury Criterion (HIC) and the Chest Severity Index (CSI). To determine the influence of the upper anchor point position, characteristics, trends, and peak values of these variables were examined for each simulation. Additionally, traces of head excursions occurring in the horizontal plane were generated and examined as a part of this evaluation. Although acceleration and displacement values for other body segments were observed, the data relative to the head was used in this analysis, since often the kinematics of the head and neck are most critical to the level of injury severity. Forces developed in the occupant restraints (i.e., lap and shoulder belts) were also determined for each simulation.

With the data described above for each of the shoulder belt anchorage scenarios, it is possible to compare the effects of anchor location on the effectiveness of the occupant restraint system.

RESULTS

Variation in x coordinate

Three simulations that maintained constant y and z coordinates of the upper anchor point at −24 in (−61 cm) and −179.1 cm, respectively, were run while varying the x coordinate through 10.7 in (27.05 cm), −1.35 in (−3.43 cm), and 13.35 in (−33.91 cm). Graphs in **Figure 6** and data in **Table 1,** describing peak values of various parameters with respect to the x-coordinate position, generally show a decrease or improvement in parameter values as the anchor point is moved rearward. Injury criterion such as the HIC and HSI have values as high as 1,548 and 1,793, respectively, for x=10.7 in (27.05 cm), but are seen to decrease to 765 and 945, respectively, with moving the anchor point rearward to x=−13.4 in (−33.91 cm). Changes of this order of magnitude are significant in these injury criteria and may represent the difference between a severe and minor head injury, as the upper HIC limit allowed by the FMVSS in vehicle design is 1,000 (6).

Peak relative displacement of the head in the x direction can also be seen to decrease when the upper anchor point is moved rearward. However, upon review of head displacement in the y direction, **Table 1** and **Figure 6** show an initial decrease, followed by an increase with a more rearward position (x=−13.4 in or −33.91 cm) of the upper anchor point. To further

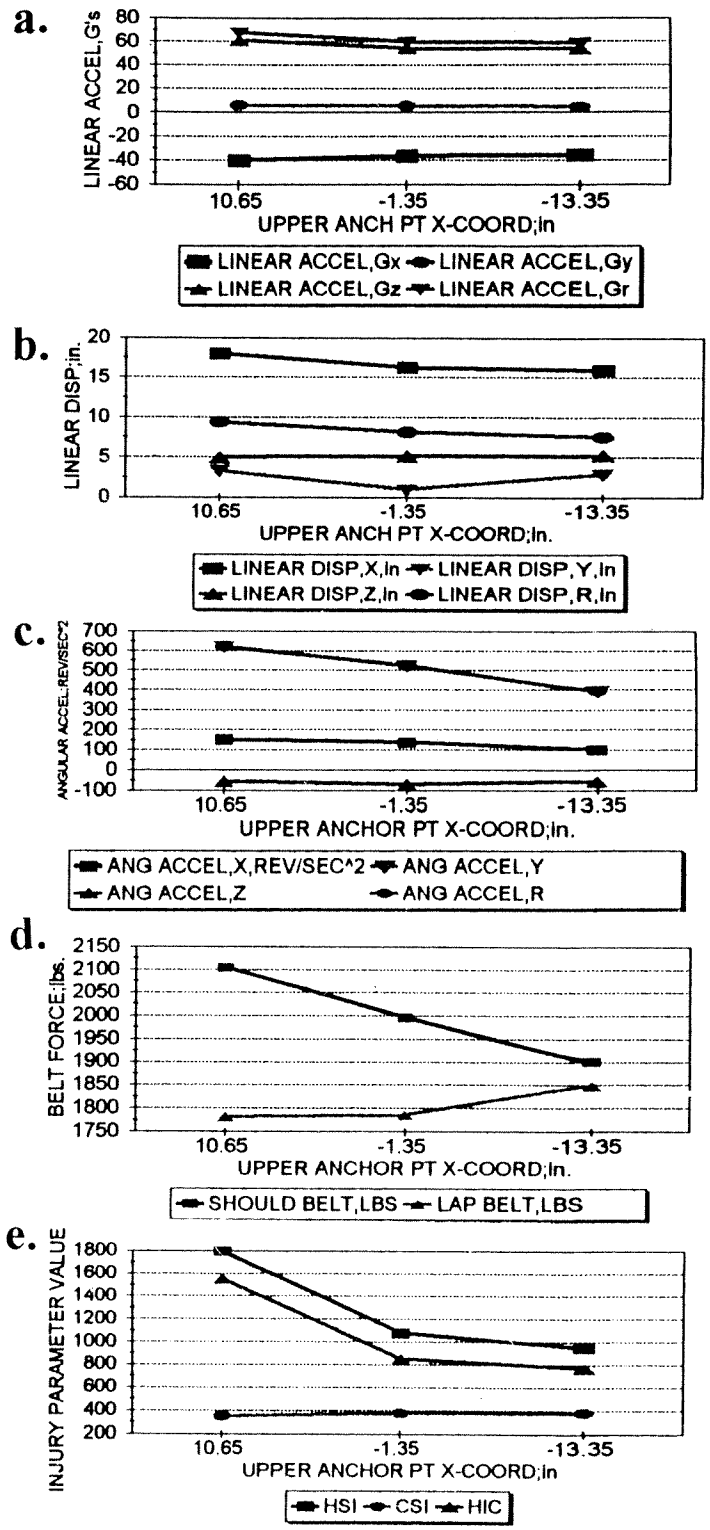

Figure 6.
Effects of varying upper anchor point in x direction. **a.** Linear acceleration of head vs upper anchor x coordinate. **b.** Linear displacement of head vs upper anchor x coordinate. **c.** Angular accelateration of head vs upper anchor point x coordinate. **d.** Occupant restraint forces vs upper anchor point x coordinate. **e.** Injury parameters vs upper anchor point x coordinate.

Table 1.
Peak values upon varying upper anchor pt location in x-direction.

Upper Anchor Pt Location (in)			Linear Head Acceleration (Gs)			Linear Head Displacement (in)				Injury Parameter			Occup Restraint Forces (lb)		Angular Head Accel (Rev/s^2)	
X	Y	Z	Gx	Gz	Gr	X	Y	Z	R	HSI	CSI	HIC	LAP	SHOULDER	Y″	R″
10.7	−24	−70.5	−40.8	60.8	67.3	17.9	3.2	4.9	9.3	1793	346	1548	1781	2104	616.4	620.9
−1.35	−24	−70.5	−36.7	53.7	59.6	16.2	0.9	5.1	8.1	1074	373	847	1785	1995	519.4	523
−13.4	−24	−70.5	−36.1	53.5	58.6	15.9	2.8	5.2	7.5	945	378	765	1848	1900	390.8	392.9

analyze this head motion, head excursion in the xy horizontal plane, was plotted over the entire 240 msec duration, and is shown in **Figure 7.** Indeed, this plot shows that despite a slight decrease in the x-directional displacement, there is an increase in the head's y displacement as the anchor is moved rearward. It is easy to see from this figure that the head excursion pattern in the xy plane is minimized for the case of x=1.35 in (−3.43 cm) when comparing these simulation runs.

A review of the resultant linear acceleration of the head, as denoted by Gr (**Figures 6** and **8**) also shows a desirable decrease as the anchor point is moved rearward. The peak resultant linear acceleration at the most rearward anchor point is 58.6 g, while in the most forward position it increases to 67.3 g. Although this only represents the peak acceleration values, it can be concluded that the duration of higher accelerations is also reduced by moving the anchor rearward as is evidenced by the sharp decline in the HIC value, which is proportional to the integral of acceleration taken over a period of time which maximizes HIC. Since such a large change occurs with variations in the anchor's x coordinate, and the HIC value associated with the anchor in its most forward position (x=10.7 in or 27.2 cm) exceeds the allowable FMVSS HIC value of 1,000, an acceleration time history for each of the x-coordinate anchor positions is provided in **Figure 8.** HIC values are calculated by integrating between 65 msec and 120 msec for each of the three anchor scenarios using the Injury Criteria routine provided in the Dynaman simulation program. As shown by **Figure 8,** the largest area under the curve is represented by the anchoring scenario where x=10.7 in (27.2 cm), producing a correspondingly higher HIC value as compared to the other x-varying anchor scenarios.

Figure 6 also indicates that the shoulder belt forces decrease with moving the anchor point rearward. These forces range from a high of 2,100 lb (952.5 kg) with the anchor point in the most forward position (x=10.7 in or 27.05 cm) to a low of 1,900 lb (861.8 kg) when the anchor is in the aftmost position of x=−13.4 in (−33.91 cm).

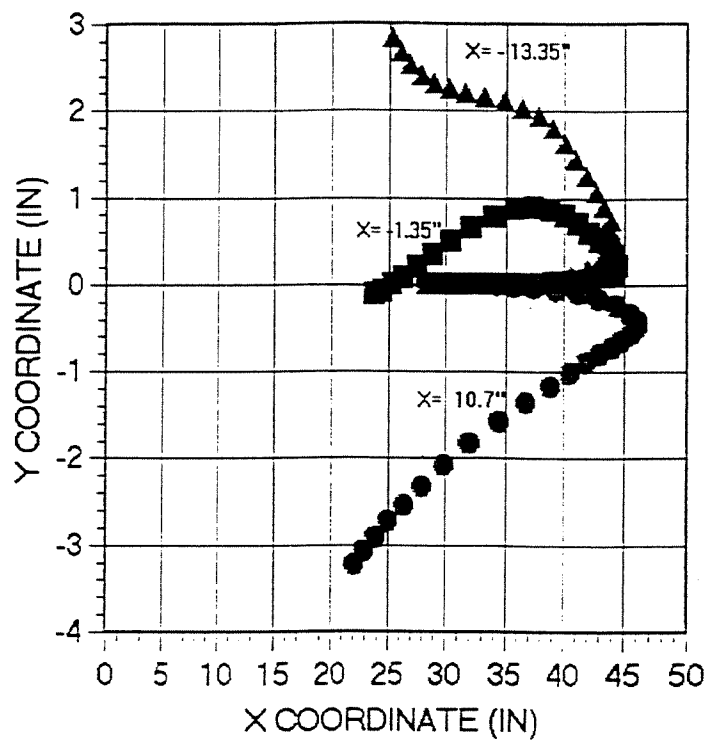

Figure 7.
Head excursion in horizontal (xy) plane when varying x coordinate.

Variation in the y coordinate

As with the simulations to evaluate the effects of varying the x coordinate of the anchor point, a similar set of simulations was conducted to evaluate the impact of changing the y-coordinate location of the anchor point. In this case, the values of the x and z coordinates were maintained (at x=10.7 in or 27.05 cm and z=−70.5 in or −179.1 cm) while simulations were run

Journal of Rehabilitation Research and Development Vol. 33 No. 3 1996

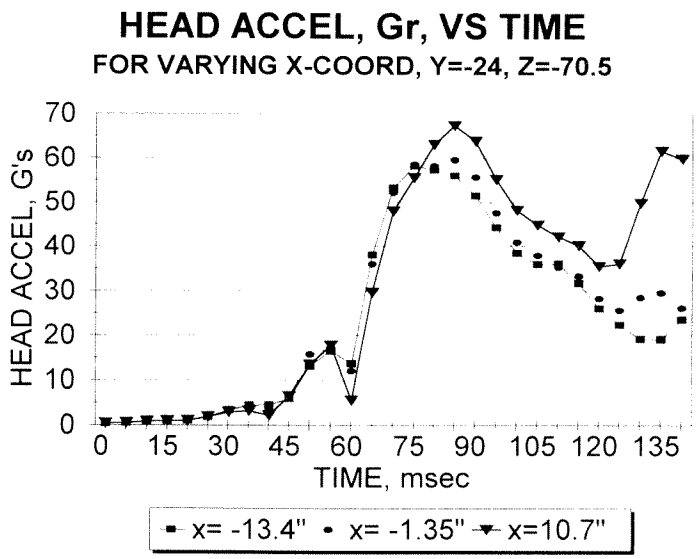

Figure 8.
Acceleration time histories for varying x-coordinate anchor position.

for y=−19.6 in (−49.8 cm), −24 in (−61 cm), and −28.5 in (−72.4 cm). These values of y were arrived at by varying 5° clockwise, 0°, and 5° counterclockwise from the FMVSS optimum comfort angle of 55°, as measured from the sternum reference horizontal plane to the shoulder belt. Therefore, simulations were conducted at belt angles of 50°, 55°, and 60° as viewed from the frontal plane. Graphs similar to those generated for variation in the x direction are shown for changes in the y direction in **Figure 9,** with data presented in **Table 2.** A corresponding trace of head excursions is provided in **Figure 10.**

With y=−19.6 in (−49.8 cm) being the point closest to the occupant's medial plane, and y=−28.5 in (−72.4 cm) the farthest from the medial plane, it can be seen from **Figure 9** that moving the anchor point away from the medial plane results in a noticeable increase in the y displacement of the head. **Figure 10,** which provides detail of the actual motion of the head, shows the increased excursion to the occupant's right side (y direction) when the anchor point is moved outward. Such motion occurs since the shoulder belt is positioned below the apex of the left shoulder, allowing the shoulder to freely rotate on frontal impact. The same figures, along with **Table 2,** also indicate an increase in the x displacement of the head with an outward movement of the anchor point.

Injury criteria for this set of simulations show negligible variation with changing the anchor position.

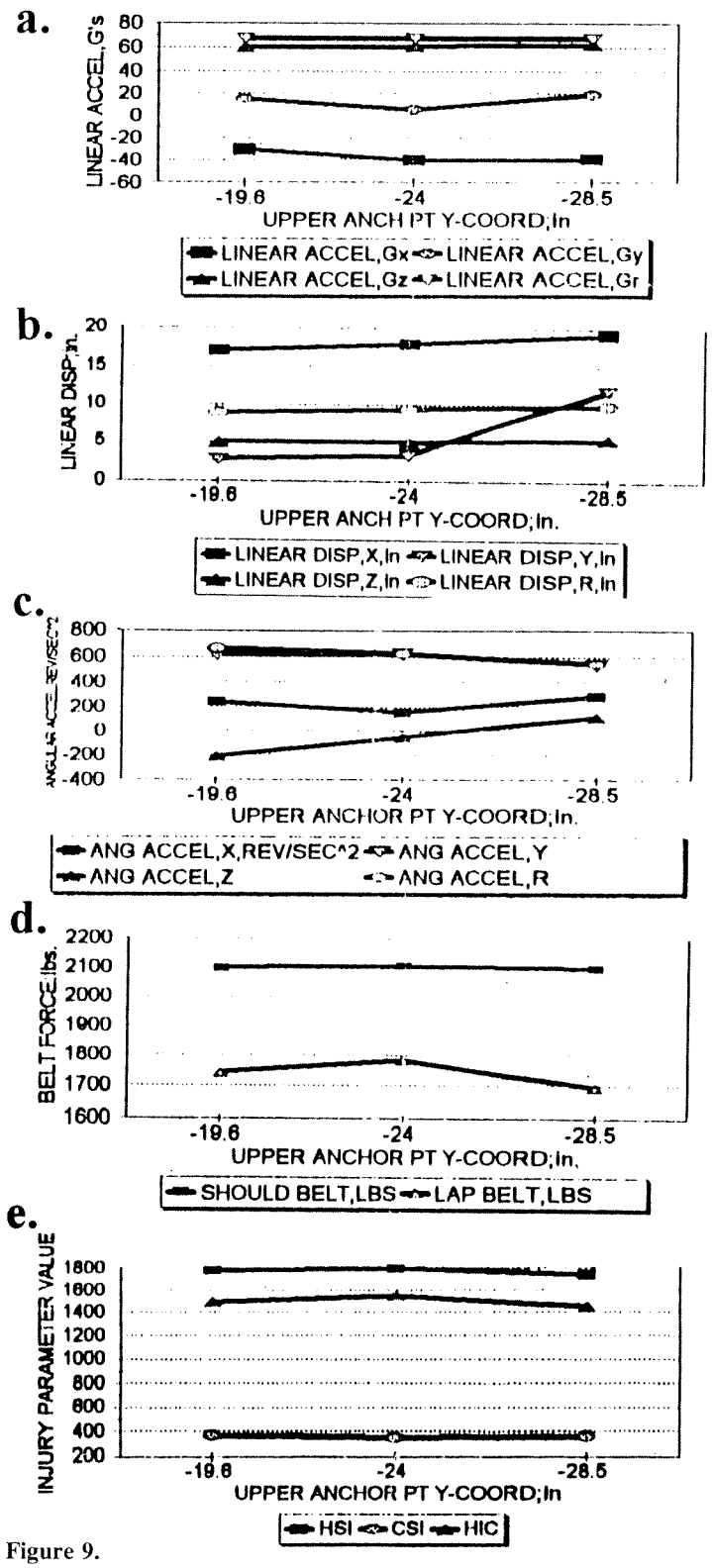

Figure 9.
Effects of varying upper anchor point in y direction. **a.** Linear acceleration of head vs upper anchor y coordinate. **b.** Linear displacement of head vs upper anchor y coordinate. **c.** Angular accelateration of head vs upper anchor point y coordinate. **d.** Occupant restraint forces vs upper anchor point y coordinate. **e.** Injury parameters vs upper anchor point y coordinate.

Table 2.
Peak values upon varying upper anchor pt location in y-direction.

Upper Anchor Pt Location (in)			Linear Head Acceleration (Gs)			Linear Head Displacement (in)			Injury Parameter				Occup Restraint Forces (lb)		Angular Head Accel (Rev/s^2)	
X	Y	Z	Gx	Gz	Gr	X	Y	Z	R	HSI	CSI	HIC	LAP	SHOULDER	Y″	R″
10.7	−19.6	−70.5	−30.7	59.8	67.3	17	2.7	4.9	8.8	1777	366	1491	1740	2098	615.8	663
10.7	−24	−70.5	−40.8	60.8	67.3	17.9	3.2	4.9	9.3	1793	346	1548	1781	2104	616.4	620.9
10.7	−28.5	−70.5	−40.1	61.7	67.2	19.1	11.8	5.3	9.8	1733	360	1446	1691	2096	535	539

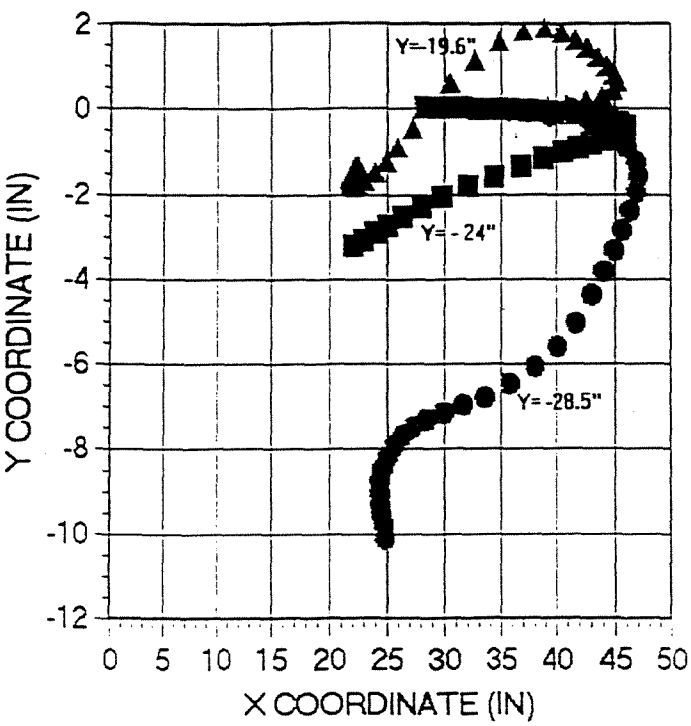

Figure 10.
Head excursion in horizontal (xy) plane when varying y coordinate.

Variation in z coordinate

Simulations to evaluate the effect of moving the upper anchor point either upward or downward from the baseline case were conducted with x=10.7 in (27.05 cm) and y=−24 in (−61 cm). Z-coordinate points were derived by varying 5° in either direction from the FMVSS recommended shoulder belt comfort angle of 55° as measured from the sternum reference horizontal plane.

Table 3 and **Figure 11** show the tabular and graphical results found while varying the z coordinate of the upper anchor point. Increasing the height of the anchor point (more negative z-coordinate value) produces increases in most parameters except head excursion in the y direction. Noticeable increase occurs in the angular acceleration of the head about the y axis with raising the anchor point. In fact, the anchor position where x=10.7 in (27.05 cm), y=−24 in (−61 cm) and z=−74 in (−188.0 cm) produces an angular acceleration of the head about the y axis equal to 684 rev/sec^2, the largest of all evaluated positions. Similarly, head injury criteria are also the largest with HSI=2,045 and HIC=1,712, when the anchor is at this same position (z=−74 in or −188.0 cm).

Upon reviewing the head displacement pattern in the horizontal plane, shown in **Figure 12,** it is seen that having the anchor point of the shoulder belt in the highest position (i.e., z=−74 in (−188.0 cm) and a belt angle of 60°) provides the greatest restriction to head excursion in the y direction. When the anchor point is lowered to z=−65.1 in (−165.4 cm, belt angle = 50°), the shoulder belt no longer passes over the clavicle and instead crosses the torso below the shoulder apex, which allows the shoulder to rotate free from the belt and results in increased head excursion in the transverse plane. Head excursion in the y direction, associated with the low anchor point (z=−65.1 in or −165.4 cm), is 6.4 in (16.3 cm), whereas the highest anchor point (z=−74 in or −188.0 cm) produces head excursions of 2.8 in (7.1 cm).

DISCUSSION

Variation in x coordinate

As indicated by the results obtained, moving the upper anchor point of the shoulder belt rearward improves the wheelchair occupant's crash protection. Decreases occurring in the head's linear and angular acceleration when the anchor point is moved rearward are significant and could represent a difference in the

Journal of Rehabilitation Research and Development Vol. 33 No. 3 1996

Table 3.
Peak values upon varying upper anchor pt location in z-direction.

Upper Anchor Pt Location (in)			Linear Head Acceleration (Gs)			Linear Head Displacement (in)				Injury Parameter			Occup Restraint Forces (lb)		Angular Head Accel (Rev/s^2)	
X	Y	Z	Gx	Gz	Gr	X	Y	Z	R	HSI	CSI	HIC	LAP	SHOULDER	Y″	R″
10.7	−24	−65.1	−37.7	55.4	61	17	6.4	5.3	8.4	1108	395	849	1774	2079	509.4	510.2
10.7	−24	−70.5	−40.8	60.8	67.3	17.9	3.2	4.9	9.3	1793	346	1548	1781	2104	616.4	620.9
10.7	−24	−74	−43	63.7	70.1	18.5	2.8	4.7	9.5	2045	375	1712	1800	2099	684	702.2

severity of an injury in such a crash. The most rearward positioning locates the shoulder belt in such a way that contact with the shoulder is increased, which serves to better couple the occupant with the vehicle. A closer coupling of the occupant and vehicle through the restraint system will ultimately increase the occupant's potential for "riding down the crash" at the same rate as the vehicle structure; thereby reducing the amplitude of the occupant's crash pulse. In effect, moving the anchor point of the shoulder belt rearward approaches the anchoring configuration of an integrated seat that anchors the shoulder belt just above the occupant's shoulder and has been shown to provide improved crash protection (7).

Although it is interesting to simulate and review the effects of various anchor points in the direction parallel to travel, outside of the laboratory, transporters are usually limited in the availability of structurally suitable anchor points. Bus and van window locations, positioning of seating, and the structural integrity of the vehicle often reduce anchor point options to those which are other than optimal.

Variation in y coordinate

Review of results that move the upper anchor point inboard or outboard in the frontal plane indicate that a more inboard positioning of the anchor (i.e., crossing the torso closer to the neck), significantly reduces head excursion in the y direction. When the anchor point is moved outboard, the shoulder belt no longer passes over the clavicle but instead crosses the upper torso at a point below the shoulder. This positioning permits the shoulder to rotate freely, resulting in increased head and upper torso excursions.

Linear accelerations of the head vary significantly across simulations which alter the y coordinate of the anchor point. Injury criteria and angular acceleration of the head decrease slightly with moving the anchor point outboard, since less force is applied by the shoulder restraint in this scenario.

Varying the anchor point in the y direction, or perpendicular to the direction of travel, is also often limited in actual transport situations due to the physical constraints presented by the wheelchair and vehicle. Factors such as the seat width of the wheelchair and its positioning relative to the outside wall of the vehicle influence the location of the upper anchor point of the shoulder belt in the transverse plane. For example, if a 22 in (55.9 cm)-wide wheelchair is to be transported facing forward in an ADA compliant space of 30 in (76.2 cm) wide x 48 in (121.9 cm) long, with its inboard wheel aligned with the bus aisle, then the y coordinate of the anchor point (on the outside wall) will be set at −19 in (−48.3 cm); ADA width 30 in (76.2 cm) minus half of wheelchair width 11 in (27.9 cm). Obviously, changing any of these characteristics will cause a corresponding change in the y coordinate of the anchor point.

Variation in z coordinate

Varying the shoulder belt angle through 50, 55 and 60° by adjusting the height of the anchor point shows that a higher anchor point location causes the shoulder belt to cross the torso closer to the neck, which produces an increase in head acceleration and injury criteria. Angular acceleration of the head about the y axis of 684 rev/sec^2, and a HIC value of 1,712 are the highest of the values produced for all simulations, and are thought to be unacceptable based upon the FMVSS limit of 1,000 for HIC. However, a lower anchor point of z=−65.1 in (−165.4 cm) allows for increased head excursion in the y direction since, as found with moving the anchor point outboard, the shoulder belt no longer crosses the torso at the center of the clavicle, passing instead outboard of the clavicle's midpoint.

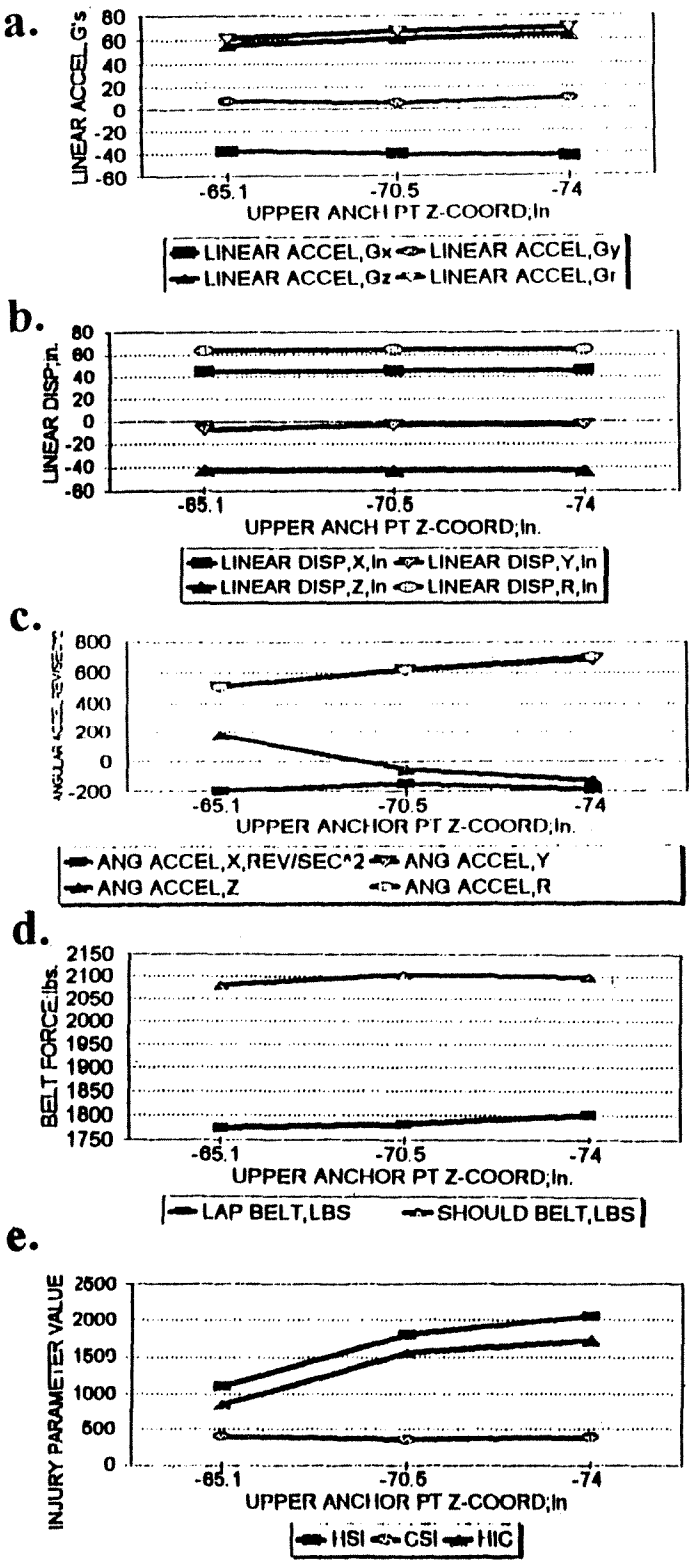

Figure 11.
Effects of varying upper anchor point in z direction. **a.** Linear acceleration of head vs upper anchor z coordinate. **b.** Linear displacement of head vs upper anchor z coordinate. **c.** Angular accelateration of head vs upper anchor point z coordinate. **d.** Occupant restraint forces vs upper anchor point z coordinate. **e.** Injury parameters vs upper anchor point z coordinate.

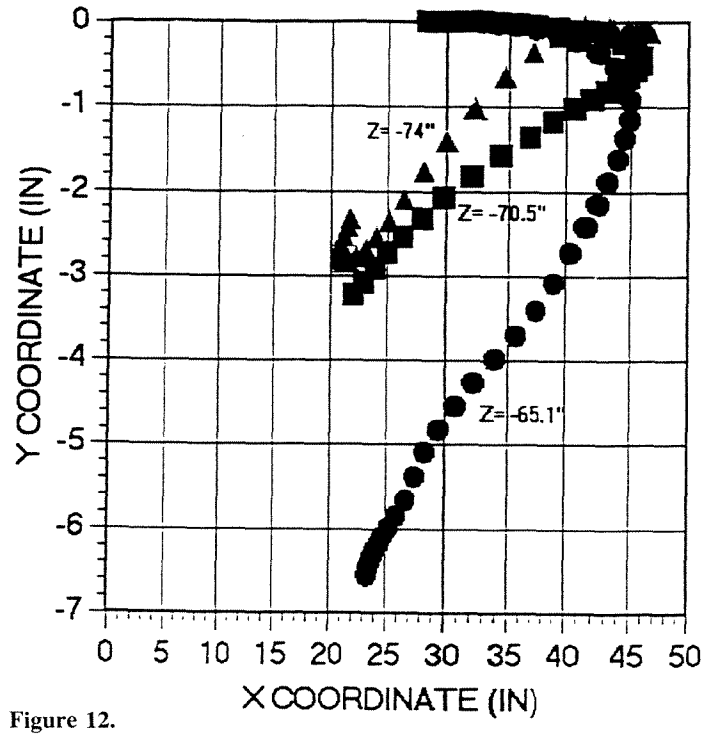

Figure 12.
Head excursion in horizontal (xy) plane when varying z coordinate.

As with variations in the x and y coordinates of the anchor point, only limited options exist to locate the height of the anchor in an actual transit situation. Typically, in fixed route or paratransit vehicles, the anchor point will be secured to vertical stanchions separating windows, or to the structure just above the window, depending upon the structural strength of these members. Where suitable vertical structure is not available for anchoring, the height of the anchor is then often limited to a point above the windows. In buses, this point is likely to be 5 ft (152.4 cm) above the floor or higher, introducing an unnecessary length of belt webbing for women and children who typically have shorter sitting heights.

CONCLUSION

As indicated by the results obtained, moving the upper anchor point of the shoulder belt point rearward producing a shallow belt angle beyond the shoulder in the xz (longitudinal) plane, improves the wheelchair occupant's crash protection. Decreases occurring in the head's linear acceleration when the anchor point is moved rearward are significant and could represent a

difference in the severity of an injury as evidenced by the changes in injury criteria. The most rearward positioning locates the shoulder belt in such a way that contact with the shoulder is increased; this serves to better couple the occupant with the vehicle. A closer coupling of the occupant and vehicle through the restraint system increases the occupant's potential for "riding down the crash" at the same rate as the vehicle structure; thereby reducing the occupant's crash pulse. In effect, moving the anchor point of the shoulder belt rearward serves to approach the anchoring configuration of an integrated seat that anchors the shoulder belt just above the occupant's shoulder, providing improved crash protection.

When comparing the results of all conducted simulations, it is seen that for a 50th percentile male, or Hybrid III dummy, undergoing a 30 mph, 20 g frontal crash, an upper anchor point with coordinates x=−13.4 in (−33.91 cm), y=−24 in (−61 cm), and z=−70.5 in (−179.1 cm) provides the best crash protection. This anchor point produces a shoulder belt angle of 55° with a horizontal plane taken through the sternum reference, and is located approximately 3 ft (91.4 cm) behind the occupant's shoulder, resulting in a belt angle of 27° in the xz plane. This anchor configuration provides a shallow angle beyond the shoulder in the xy plane; thereby closely coupling the occupant to the vehicle. With the upper anchor point in this location, the resulting HIC value of 765, and the head acceleration in the z direction of 53.5 g, are within existing FMVSS HIC requirements of 1,000 and proposed safety standards of Gz less than 70 g. Conversely, many of the other modeled anchor points do not meet these requirements. Additionally, this anchor point is optimal in that it limits the forward (x direction) head displacement to 15.9 in (40.4 cm), the smallest forward excursion of all modeled anchor points. However, as with any complex analytical model, results of the findings should be verified through the use of actual sled impact testing.

Although this model has been developed based upon the Hybrid III dummy representing a 50th percentile male, it is common to find wheelchair occupants of size and stature other than that of the 50th percentile male. Altering the physical characteristics of the occupant to represent a smaller individual or child, could have a significant impact on the crash protection offered by these same anchor points. Therefore, similar models should be compiled and validated through sled testing to simulate wheelchair occupants other than the 50th percentile male. Furthermore, models representing actual production wheelchairs, rather than the surrogate wheelchair used in this study, should also be conducted to provide a more realistic simulation. Additional useful information can also be gained by subjecting these same models to oblique frontal crashes, since in many crash scenarios impact is at an angle other than 0°.

However, important findings regarding wheelchair transportation safety can be inferred from this study which utilizes the surrogate wheelchair model:

1. Anchoring conditions which may be found in fixed or demand route vehicles, may produce HIC values in excess of the FMVSS allowable limit of 1,000.
2. Variations in the anchor point of the shoulder belt lead to notable changes in occupant restraint effectiveness, and hence, occupant dynamics. Occupant dynamics associated with certain anchoring configurations are indicative of lap and shoulder belts not providing the level of protection anticipated from these restraints.
3. Relocating the shoulder belt anchor point rearward, creating a shallow belt angle in the longitudinal plane beyond the shoulder, improves crash protection. Therefore, increasing the height of the anchor point should be coupled with moving the point rearward, to maintain a shallow angle beyond the shoulder.
4. Standards which prescribe allowable forward head excursion should also be concerned with head excursions which occur in a direction perpendicular to the line of travel since certain anchoring conditions may exacerbate this head displacement.
5. Although variations in physical size of the occupant were not explored as a part of this study, a fixed shoulder belt anchor point will lead to variations in occupant belt fit with different-sized occupants. These variations in belt fit will produce differing, and in some cases undesirable, levels of crash protection. In circumstances where the occupant size varies (as is the case with most public transportation environments), it is recommended that an adjustable anchor point be provided to allow for optimal belt positioning.

Since in public transportation the anchor point of the shoulder belt is generally located and permanently fixed at the time of installation, it is of paramount importance that additional study and testing of the shoulder belt anchorage be conducted, as it can have a large impact on the wheelchair occupant's crash protec-

tion. Through research and standards development regarding wheelchair transportation, studies such as this must be conducted in an effort to optimize the upper location of the anchor point so that we can begin to offer those being transported in wheelchairs the same safety afforded to the nondisabled transit rider.

REFERENCES

1. National Highway Transportation Safety Administration (NHTSA). 49 CFR Part 571.210, occupant crash Protection. Washington, DC: US Department of Transportation, 1991.
2. International Standards Organization. ISO draft standard, wheelchair tiedown and occupant restraints systems for motor vehicles. October 1994.
3. University of Virginia/UMTRI. Interlaboratory sled impact testing for ISO working group 6 of TC 173/SC1, wheelchair tiedown and occupant restraint systems. November 1993.
4. NHTSA. 49 CFR Part 571, FMVSS occupant crash protection, advanced notice of proposed rulemaking. Washington, DC: US Department of Transportation, 1992.
5. Digges K, Bertocci G, Hobson D. Fitting motor vehicle shoulder belts to wheelchair occupants: report #1. University of Pittsburgh, NIDRR, Grant No. H113E30005, 1994.
6. NHTSA. 49 CFR Part 571.208, FMVSS crash protection. Washington, DC: US Department of Transportation, October 1993:455–6.
7. Lynch T. Integrated seat adds safety, design convenience, Des News 1995:43(10):43.