DEVELOPMENT OF MANUAL PEDIATRIC TRANSIT WHEELCHAIR DESIGN GUIDELINES USING COMPUTER SIMULATION

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ABSTRACT

Many children must use their wheelchair as a seat while traveling in a motor vehicle. Under crash conditions these wheelchairs are subjected to higher loads than those experienced during normal mobility and warrant special design consideration. Using a previously validated pediatric wheelchair model, our study investigated wheelchair loading under 20g/48kph frontal impact conditions with varying wheelchair characteristics. Our model utilized a four-point tiedown secured pediatric manual wheelchair with a seated Hybrid III 6-year-old ATD, restrained using a three-point occupant restraint. Securement point loads were found to be as high as 4355 N for the rear and 6988 N for the front, with maximum seat pan loading of 1374 N and seat back loading of 1992 N. Maximum rear wheel loads were found to be 5098 N, with caster loading as high as 2013 N. These findings which are different from those of adult wheelchairs should provide guidelines for manufacturers designing technologies for safe pediatric wheelchair transportation.

KEYWORDS: pediatric transit wheelchair, computer crash simulation, wheelchair transportation safety

BACKGROUND

When children with disabilities are transported, they often remain seated in their wheelchairs in vehicles. Under crash conditions, these wheelchairs are subjected to higher loads than those experienced during normal mobility and warrant special design consideration. Currently, no study exists that provides guidelines to the manufacturers designing pediatric transit wheelchairs. Wheelchair manufacturers have begun producing pediatric transit wheelchairs in compliance with the ANSI/RESNA WC-19 standard [1]. At last count, there were approximately nine manufacturers who produce pediatric transit wheelchairs, including transit strollers, with the number continuously increasing. To promote the development of pediatric transit wheelchairs, guidelines aiding manufacturers in the design of these products would be useful.

Due to the rapid growth of children, pediatric wheelchairs must be adoptable to accommodate for their growth as third party payers often only provide new wheelchairs every fourth or fifth years. Wheelchair seats, seat backs, wheels, frames, and footrests are usually adjustable on most pediatric wheelchair models. Previous studies on adult transit wheelchairs have shown that changing of wheelchair settings, such as back angle, do have an effect on crash loads imposed upon a wheelchair [2-3]. In this study, the loads imposed upon a pediatric manual wheelchair during a frontal motor vehicle crash under different wheelchair setup scenarios were investigated using a previously validated computer crash simulation model [4].

RESEARCH OBJECTIVE

The goal of this study is to investigate the loads imposed upon a pediatric manual wheelchair under 20g/48kph frontal impact conditions at different wheelchair setup scenarios.

METHODS

A previously validated MADYMO computer simulation model representing a Hybrid III 6-year-old ATD seated in a manual pediatric wheelchair, Sunrise Medical Zippie (Longmont, CO), and subjected to a

20g/48kph frontal impact was used in this study (see Figure 1) [4]. In the model, the wheelchair was secured to the sled platform using a surrogate four-point, strap-type tiedown, and the ATD was restrained with vehicle-anchored, three-point occupant restraint belts.

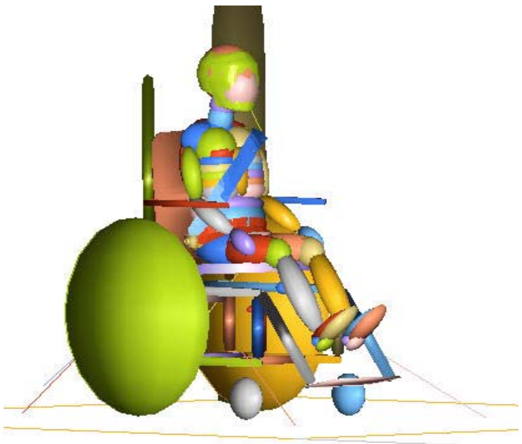

Figure 1 Computer model representing Zippie pediatric manual wheelchair with a seated Hybrid III 6-year-old ATD

The rear axle positioning and seat back angle are adjustable with the Zippie wheelchair. Adjusting the rear axle positioning can change the seat-to-back intersection location relative to the rear hub, as well as the rear securement point vertical location. To study the effect of adjustable features on loads imposed upon the wheelchair, a parametric sensitivity analysis was conducted. Each parameter (seat back angle, rear tiedown point vertical location, and seat-to-back intersection horizontal location) was varied independently while all other parameters remained at their baseline. Baseline conditions of the wheelchair model are described in Table 1. The seat back angle (SBA) was varied from -5º to 35º in 10° increments, the rear securement point (SP) vertical location was varied from 200 mm below the wheelchair center of gravity (CG_{WC}) to 100 mm above the CG_{WC} in 100 mm increments, and the seat-to-back intersection (STBI) horizontal location was varied from 100 mm behind the rear hub to 100 mm in front of the rear hub in 50 mm increments. The MADYMO model was programmed to calculate the forces on the wheelchair seating system (seat pan and seat back), securement points (front and rear), and wheels (front and rear) during the simulation.

Table 1 Zippie Wheelchair Baseline Conditions

Wheelchair Weight	18.6 kg
Rear Hub Height	280 mm above floor
Wheelchair CG (CG_{WC}) wrt Rear Hub	188 mm fore; 79 mm above
Seat Back Angle	4 º
Seat Pan Angle	3 º
Seat-to-Back Intersection Location wrt Rear Hub	23 mm fore
Rear Securement Point Location	44 mm below CG_{WC}

RESULTS

Among different wheelchair setup scenarios, the seat pan force was influenced the most by the wheelchair rear securement point location: the seat pan resultant force ranged from 931 N to 1374 N (32 % difference), and the seat pan shear force ranged from 183 N to 284 N (36 % difference) (see Table 2).

The greatest difference between any two scenarios, Max. % difference, was expressed as ($Force_{max}$-$Force_{min}$)/($Force_{max}$) *100.

The seat back force was influenced the most by the seat back angle changes: the resultant force ranged from 1028 N to1992 N (48 % difference), and the shear force ranged from 213 N to 587 N (64 % difference) with changes in seat back angle (see Table 3). The greatest securement point forces (both front SP and rear SP) occurred when the rear securement point was positioned 100mm above the CG_{WC} (see Table 4). The rear tiedown locations also had a substantial impact on wheelchair wheel forces (both rear wheels and front casters): force on the rear right wheel ranged from 1064 N to 5098 N (79 % difference) and force on the front left wheel ranged from 95 N to 2013 N (95 % difference) (see Table 5).

Table 2 Maximum force on wheelchair seat pan: 200mm below CG_{WC} to 100mm above CG_{WC}

Rear SP position wrt CG_{WC} (mm)	Resultant (N)	Shear (N)
-200	931	183
-100	1017	196
Baseline (-44)	1039	196
0 (at CG_{WC})	1123	220
+100	1374	284
Max. % diff.	**32**	**36**

Table 3 Maximum force on wheelchair seat back: -5° to 35 ° seat back angle

Seat Back Angle (°)	Resultant (N)	Shear (N)
SBA -5	1859	463
Baseline (+4)	1609	273
SBA +15	1028	302
SBA +25	1028	213
SBA +35	1992	587
Max. % diff.	**48**	**64**

Table 4 Maximum force on wheelchair securement points: 200mm below CG_{WC} to 100mm above CG_{WC}

Rear SP position wrt CG_{WC} (mm)	Front Right SP (N)	Front Left SP (N)	Rear Right SP (N)	Rear Left SP (N)
-200	4540	2939	2319	2780
-100	4607	3319	2860	3135
Baseline (-44)	4340	3012	3115	3470
0 (at CG_{WC})	5075	2228	3443	4069
+100	6988	1759	4355	3904
Max. % diff.	**38**	**47**	**47**	**32**

Table 5 Maximum force on wheelchair wheels: 200mm below CG_{WC} to 100mm above CG_{WC}

Rear SP position wrt CG_{WC} (mm)	Rear Right Wheel (N)	Rear Left Wheel (N)	Front Right Wheel (N)	Front Left Wheel (N)

-200	1064	914	1961	2013
-100	2106	2158	1163	1240
Baseline (-44)	3105	3150	615	696
0 (at CG_{WC})	3804	3925	237	703
+100	5098	4964	97	95
Max. % diff.	**79**	**82**	**95**	**95**

Based on the results found in this study, the maximum loads a manual pediatric wheelchair experience during a 20g/48kph frontal impact when a 6-year-old occupant is seated in the wheelchair is presented in Table 6.

Table 6 Maximum force on the manual pediatric wheelchair seated with a 6-year-old ATD subjected to a 20g/48kph frontal impact

WC components	**Force (N)**
Seat pan	1374
Seat back	1992
Front securement point	6988
Rear securement point	4355
Rear wheel	5098
Front wheel	2013

DISCUSSION AND CONCLUSIONS

Using the previously validated computer simulation model representing a Hybrid III 6-year-old ATD seated in a manual pediatric wheelchair and subjected to a 20g/48kph frontal impact, the loads imposed upon a pediatric manual wheelchair under different wheelchair setup scenarios were evaluated. Securement point loads were found to be as high as 4355 N for the rear and 6988 N for the front, with maximum seat pan loading of 1374 N and seat back loading of 1992 N. Maximum rear wheel loads were found to be 5098 N, with caster loading as high as 2013 N.

Compared to the loads found in the previous studies on adult wheelchairs with adult occupants, loads presented in this study for a manual pediatric wheelchair seated with a 6-year-old occupant were much lower [2] [5-7]: on average, the loads resulting from the components of pediatric wheelchair model (including wheelchair seating system, securement points, and wheels) were 82.1 % lower than those resulting from the components of adult power wheelchair model [2] [5] and 73.2 % lower than those resulting from the components of adult manual wheelchair model [6-7]. Designing a pediatric transit wheelchair or other products for pediatric wheelchair transit might be easier to achieve than those designed for adults since the loads expected to be imposed on a product during a frontal impact are much lower for a pediatric wheelchair.

This is the first study to evaluate pediatric wheelchair loading associated with a frontal impact crash. Although the results presented in this study were derived based on the mathematical modeling techniques, the study results will provide wheelchair and seating manufacturers designing products for pediatric population with insight as to the magnitude and types of forces that can be imposed upon their products in a frontal crash.

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