Background/Introduction
In 1990 the US Congress enacted the Americans with Disabilities Act (ADA) prohibiting discrimination against people with disabilities in employment practices, public accommodations and telecommunication services. Transportation services by legislative definition fall within the public accommodations category. Therefore, public and private transportation service providers must accommodate persons seated in their wheelchairs who wish to travel. More recently the 2001 New Freedom Initiative has cited integration of persons with disabilities in the workforce and the community as funding and research priorities, specifically noting ‘transportation’ as a critical factor in meeting this priority. The Director of Project Action reinforced this need indicating that one third of the 25 million transit dependent people with disabilities report inadequate transportation as a significant barrier to integration. Such governmental priorities will continue to escalate the numbers of wheelchair users seeking transportation.

Wheelchair users who are unable to transfer to a motor vehicle seat during transport must rely upon their wheelchair to function as a vehicle seat. Unfortunately design characteristics that make a wheelchair suitable for mobility often are in direct conflict with characteristics which define an acceptable motor vehicle seat. Typically wheelchairs are intended to serve as a “mobility aid”, while motor vehicle seats are designed to secure their restrained passenger or driver to the motor vehicle, which in turn provides mobility. Motor vehicle seats also incorporate numerous design features that protect an occupant in a crash and accordingly, extensive research has been dedicated to the design and development of vehicle seats. Motor vehicle seats must also meet stringent government Federal Motor Vehicle Safety Standards. Unfortunately, only limited effort has been devoted to-date to the research, development and design of wheelchairs and their seating systems intended to serve as vehicle seats.

The past decade has, however, seen a flurry of activity related to wheelchair transportation standards development. Voluntary industry standards that address both wheelchair securement in motor vehicles and wheelchairs used for transport on motor vehicles have been developed and adopted both nationally and internationally. One of the leading test facilities in the US (University of Michigan Transportation Research Institute) reports that over 73 manual wheelchairs, 27 power wheelchairs and 16 securement systems were frontal impact tested last year in accordance with either SAE or ANSI/RESNA Standards. Clearly manufacturers have embraced the standards and have taken measures to begin offering transport-safe products. Development and compliance with these standards represents the critical first steps towards increasing the safety of those traveling seated in their wheelchairs. However, despite the tremendous effort that has been made towards industry standards, much work remains to bring the safety of persons traveling in wheelchairs to a level equivalent to that of a persons traveling seated in motor vehicle seats.
Review of the Science
Standards
A recent summary of wheelchair transportation standards was compiled by Hobson. The development of wheelchair transportation standards, both nationally and internationally, has been divided into two major categories; (1) wheelchair securement and occupant restraint and (2) wheelchair crashworthiness. Wheelchair securement and occupant restraint systems are addressed in the United States through the Society of Automotive Engineers (SAE) J2249 Wheelchair Tiedown and Occupant Restraint Systems (WTORS) Standard and internationally through the International Standards Organization (ISO) 10542 Wheelchair Tiedowns and Occupant Restraints Standard. Both of these standards define design requirements, instructions to users and test requirements for WTORS. As a part of compliance with these standards, WTORS must be able to secure a 85 kg (187 lb) surrogate wheelchair and restraint a 50th percentile male test dummy during a 20g/48kph frontal impact test event. Test criteria consist of maintaining WTORS integrity and meeting limitations of wheelchair and occupant excursion.

The second category of wheelchair transportation standards, wheelchair crashworthiness, is addressed nationally through the ANSI/RESNA WC-19 Wheelchairs Used as Motor Vehicle Seats Standard, and internationally through the ISO 7176/19 Wheelchairs Used as Motor Vehicle Seats Standard. These standards, which focus on the use of a wheelchair as a motor vehicle seat, propose design requirements, instructions to users and test procedures for wheelchairs intended for transportation. A significant design requirement established by these standards is the addition of 4 securement points on transport-safe wheelchairs which are compatible with end fittings of strap type tiedown securement systems. This requirement was defined in response to difficulty in properly identifying locations on the wheelchair for attachment of tiedowns. Frontal sled impact testing is perhaps the most stringent of tests to be conducted for compliance with ANSI/RESNA WC-19 and ISO 7176/19. This testing subjects an appropriately sized wheelchair-seated test dummy to a 20g/48kph frontal impact sled test. In the ANSI/RESNA WC-19 test protocol, the wheelchair is secured and the occupant is restrained using a surrogate WTORS. (The ISO 7176/19-DIS test protocol permits wheelchair securement and occupant restraint using a commercial WTORS.) ANSI/RESNA WC-19 and ISO 7176/19 test criteria assesses wheelchair integrity, as well as occupant and wheelchair kinematics.

Despite an effort by ANSI/RESNA WC-19 and ISO 7176/19 to evaluate wheelchair crashworthiness, the addition of often used after-market or optional wheelchair seating systems will invalidate wheelchair testing. Consequently, wheelchairs utilizing after-market seating systems may not be sled tested to evaluate their ability to withstand crash level forces. Additionally, replacement seating systems provided in the field which differ from those provided with a WC-19 or ISO 7176/19 approved wheelchair will invalidate compliance and will not have been tested. Therefore, methods to evaluate wheelchair seating system crashworthiness, independent of the numerous different wheelchair frames that it may be coupled with in the field, are desirable. Towards this...
end, both international (ISO) and national (ANSI/RESNA) standards groups have organized efforts to address after-market transport-safe wheelchair seating. The ISO 16480 and ANSI/RESNA Seating Devices for Use in Motor Vehicles working groups have recently begun work on this standard. Both of these groups have agreed to pursue development of independent dynamic seating test methods.

Research
Transport-Safe Wheelchairs and Wheelchair Seating
Early wheelchair transportation research primarily focused on efforts needed to advance standards development. These early studies worked toward the development of a repeatable frontal impact test using a re-usable surrogate wheelchair. As a part of the standards effort a computer simulation model was used to investigate the effects of wheelchair tiedown system characteristics, crash pulse corridor, and seated posture on tiedown and belt loading, wheelchair excursions, and occupant crash response. Although most injury research and prevention fields are driven by epidemiology-based studies detailing accident statistics, only limited data on accidents involving persons using wheelchairs as seats in motor vehicle crashes is available. A number of studies have also attempted to investigate the injury risk associated with using a wheelchair as a motor vehicle seat, investigating the effects of crash pulse, securement point location, restraint configuration and seated posture.

Supporting the fact that wheelchairs are not typically designed to sustain crash-level forces, component testing studies have shown that casters, seat attachment hardware and seat support surfaces often fail at loads similar to those imposed in a frontal impact crash. Unfortunately, design criteria to guide manufacturers in the development of transport-safe wheelchairs and wheelchair seating systems are relatively scarce. Information that exists in the literature has been largely been derived from computer simulation of frontal impact events. These studies have shown that numerous factors (e.g. rear wheelchair securement location, seat stiffness, seat angle) can influence loads that wheelchairs are exposed to in a crash. These findings suggest that manufacturer design decisions can greatly impact the crashworthiness of wheelchairs. While performance of all wheelchair components is key to occupant crash protection, seat design and integrity are of particular concern since vehicle seat characteristics and failure have been linked directly to injury risk in motor vehicle crashes. Frontal impact sled tests (20g/48kph) of commercial wheelchairs have shown seating system failures to be relatively common. Seat attachment hardware, seat support surfaces and seat backs (on rebound) are among the most common components to fail under frontal impact conditions.

Previous studies which have attempted to elucidate wheelchair seat loading under crash conditions have consisted of both computer simulation studies and limited sled testing. Computer simulation studies have shown that frontal impact seat forces are dependent upon crash pulse, rear securement point location, seat characteristics and restraint configuration. A limited series of frontal impact sled tests conducted by Gu and Roy with disc-type load cells incorporated into the ISO surrogate
wheelchair and using a Hybrid III 50th percentile male test dummy measured seat loads.
Shaw also estimated seat loading in frontal impact sled testing using pressure sensitive film placed on the seat and load cells located beneath the front wheels of commercial manual wheelchairs with various types of seating systems (i.e. sling, rigid foam mounted on plywood). In these tests Shaw estimated vertical seat loads and found that higher loads were associated with the more rigid seating systems. Recent frontal impact testing (4 tests) conducted by Bertocci and Manary using the SAE surrogate wheelchair evaluated seat loads using disc-type load cells incorporated into the wheelchair seat and also evaluated the effects of rear securement point location. This recent series of sled tests provided validation to a previously conducted computer simulation study.

While these studies provide a first approximation of wheelchair seat loading under 20 g frontal impact conditions, limitations exist. Experimental measurement techniques used in sled tests conducted by Shaw were limited since seat loads were estimated from measurements recorded at only the front wheels and did not account for that portion of the seat load which may be distributed over the rear wheels. Gu and Roy’s testing utilized measurement techniques directly assessing seat loads, but unfortunately only one sled test was conducted at the 21g/48kph level; all others were below this crash severity. Recent frontal impact tests conducted by Bertocci and Manary are also somewhat limited and can be used only as a guide since they utilize the SAE surrogate wheelchair which is more rigid than a commercial wheelchair.

While these previous studies represent a preliminary effort towards development of transport-safe wheelchairs and wheelchair seating, additional efforts are needed to advance safe wheelchair transportation. Testing and computer simulations to-date were conducted with a 50th percentile male test dummy; no studies have been conducted to evaluate seating loads associated with child-sized test dummies. Furthermore, previous studies evaluated seat loading in frontal impact conditions alone; no efforts have been undertaken to study seat loading under rear and side impact which are likely to impose very different loading conditions. Despite observed failure of seat backs during the rebound phase of frontal impact testing, no efforts have been mounted to evaluated seat back loading conditions. Wheelchair seat backs are also subjected to unique loading conditions in rear impact crashes, yet no studies have been conducted to quantify seat back or wheelchair loading in rear impact. More detailed investigative studies, such as those conducted in the automotive industry, are also needed to evaluate the effects of wheelchair seating design on injury risk. Clearly additional guidance is needed to provide wheelchair manufacturers with guidance related to seating system design for transport-safe wheelchairs. Also, research to-date has been conducted by a very limited number of researchers and academic institutions, in order for the field of wheelchair transportation to advance, academic training is clearly needed to promote more diverse research efforts.

Future Work as Identified by Standards Committee
With completion of ANSI/RESNA WC19 Wheelchairs Used as Seats in Motor Vehicles, the Subcommittee on Wheelchair and Transportation has identified the following
additional work items. These items, in priority order include: 1) completion of a companion document to provide the rationale for provisions within the standard, along with useful information for manufacturers, consumers and clinicians 2) independent testing for after-market seating systems, 3) crashworthiness of wheelchairs secured by other than 4-point tiedowns, 4) universal docking interface, 5) harmonization with ISO and CSA, 6) restraint of small children, 7) rear impact crashworthiness, 8) design criteria for secondary supports and surfaces, and 9) side impact crashworthiness. Most of these items have also been cited as priorities within the ISO Standards committees.

Summary Points

- Wheelchairs and their seating systems are key to providing adequate protection to wheelchair users in a crash.
- Voluntary Industry Standards have provided the first critical steps towards improved wheelchair user crash protection.
- Voluntary industry wheelchair transportation standards provide test methods, design guidelines, labeling and instructions to users.
- Education of consumers, clinicians and manufacturers is key to effective standards implementation.
- As compared to the motor vehicle industry, little research has been conducted related to the effects of wheelchair and wheelchair seating design on occupant protection and injury risk.
- Additional design guidelines are needed for wheelchair and seating manufacturers to develop and provide consumers with transport-safe products.
- Preliminary guidelines for wheelchair seating (not including the seat back) have been developed using computer simulation and limited sled impact testing.
- Test methods to evaluate wheelchair seating independent of a specific wheelchair frame are needed.
- Rear and side impact wheelchair and seat loading conditions have not been consider thus far. Standards groups have also defined additional work items that include addressing side and rear impact.
- No efforts have been made to quantify impact seat loading associated with children. Transport-safe wheelchair seating design criteria (frontal, rear and side impact) is needed for pediatric wheelchairs.
- Additional researchers and research training are needed to advance the wheelchair transportation field.

References


Potential Discussion Questions – Transport-Safe Wheelchair Seating

- What are the most effective means to educate consumers, clinicians and manufacturers on wheelchair transportation standards and safety issues.
- How can research interest in wheelchair transportation be increased?
- How do insurance companies and third-party payers view the “transit option” wheelchair?
- What are the industry barriers to preventing development and marketing of transport-safe seating products?
- Do rear and side impact present unique wheelchair seating design challenges?
- What should the priorities of the newly formed Seating Devices for Use in Motor Vehicles standards groups consist of?
- If an independent seating system test is developed, what does this mean in terms of the complete wheelchair system (i.e. wheelchair frame and seating system) compliance with standards?
  - Will there be a need for an independent wheelchair frame test?
  - Will manufacturers accept such an approach?
  - What are the liability issues related to this topic?