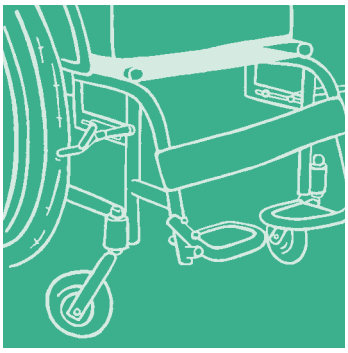

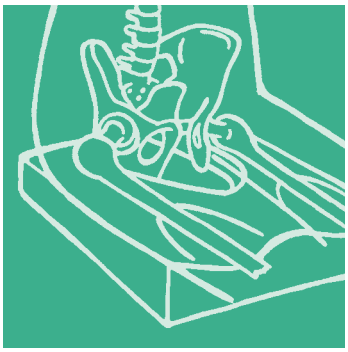

Design Considerations

for Wheelchairs used in Adverse Conditions

Last Updated: February 2018

ISWP International Society of Wheelchair Professionals

USAID FROM THE AMERICAN PEOPLE

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University of Pittsburgh scientists are working with the U.S. Agency for International Development (USAID) under a multi-year sub-award to develop the International Society of Wheelchair Professionals, a global network to ensure a level of standardization, certification and oversight, to teach and professionalize wheelchair services, and to build affiliations to put better equipment in the right hands. Since 2002, USAID has granted more than $45 million to improve wheelchairs and wheelchair services worldwide. This sub-award – Agreement No. APC-GM-0068 – was presented by Advancing Partners & Communities, a cooperative agreement funded through USAID under Agreement No. AIDOAA-A-12-00047, beginning Oct. 1, 2012.

Photo & Illustration credits: American Wheelchair Mission, 2016; APDK, 2016; Joseph Ruffing, University of Pittsburgh, 2017; Motivation Charitable Trust, 2017; Elsje Scheffler, DARE Consult 2017; Whirlwind, 2017.

About this document

This document was created to guide wheelchair designers, manufacturers, providers, users and their caregivers on design considerations for wheelchairs used in adverse environments, especially those encountered in less-resourced areas. The need for this document was identified as a high priority by the Standards Working Group (SWG) of the International Society for Wheelchair Professionals. The SWG noted that the WHO Guidelines on the Provision of Manual Wheelchairs for Less Resourced Settings provided the general guidance for the design and production of appropriate wheelchairs but lacked detailed information stakeholders need to avoid the common pitfalls for designing wheelchairs where resources are limited and conditions are adverse. A subcommittee of the SWG was formed to draft the document, and the SWG and external reviewers provided feedback remotely and during an in-person meeting hosted by UCP Wheels for Humanity in 2016.

The document, which will be revised periodically, is available on the ISWP website, Resource Hub section: http://wheelchairnet.org/iswp-library. Search for "Design Considerations."

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Introduction

A wheelchair functions as a system resolving multiple and often competing requirements, loosely grouped around mobility and posture support. A wheelchair user often must use a single wheelchair for a vast range of activities in a large range of indoor and outdoor environments. Moreover, wheelchair designs must usually serve a diverse number of individuals who each have unique mobility, environmental and postural needs. As such, it is important to keep in mind that to design a wheelchair is to manage an enormous number of interrelated compromises, and that decisions about one aspect of a wheelchair's performance typically affect other aspects.

Design Considerations is a document intended to be of assistance for a multitude of stakeholders including manufacturers desiring to develop wheelchairs for use in adverse conditions, service and delivery providers wanting to understand more about the design requirements of an "appropriate wheelchair" and consumers wanting to know more about how their wheelchair was designed and what constitutes an appropriate chair for their environment and use. This document hopefully will be a resource to all who are involved in the design and provision of wheelchairs used in adverse conditions. Design Considerations is written by a team of industry veterans including manufacturers, service providers, clinicians and users.

This document should be read and utilized in conjunction with the:

1. World Health Organization (WHO) Guidelines on the provision of Manual Wheelchairs in less-resourced settings [1]
2. World Health Organization Basic Wheelchair Service Training Package (WSTP-B) [2]
3. World Health Organization Intermediate Wheelchair Service Training Package (WSTP-I) [3]

Resourced governments and international donors of wheelchairs have played an increasingly prominent role in wheelchair provision within less-resourced regions. The adverse terrain and other environmental factors associated with less-resourced environments have brought forth a new set of challenges for designers, engineers and manufacturers. Subsequently, there now are a wide variety of frame designs, footrests, postural support devices (PSDs) and standard wheelchair components which can be specified to meet the needs of the wheelchair user, the environment and other stakeholders in the procurement and distribution network. It is up to the wheelchair designer to select an appropriate combination of properties which can appeal to the desired user group in order to create a durable and functional design. This document gives a detailed description of the different factors which should be taken into account when designing a wheelchair for use in adverse conditions, as well as suggestions for a variety of appropriate solutions. It is not intended to be a prescriptive manual for wheelchair design but, rather, a description of considerations to be taken into account when designing, manufacturing, evaluating and purchasing wheelchairs.

This document highlights the various functions of wheelchair components and gives comparisons between the common options available. This document is split into four major sections.

Section 1

Covers components which mainly interact with the environment. Factors which are prominent in this section are wear and tear as a result of continuous use in rough terrain or weathering as a result of use in wet, humid or sandy conditions. Factors affecting usability additionally are taken into account on components which can be designed or specified to allow the user to maneuver through his/her environment as easily as possible. Each component of the wheelchair is evaluated in terms of user function, environmental considerations and options of adjustability. A comparative matrix of commonly available component options gives a summary of advantages or drawbacks of different design options, as well as an evaluation of the manufacturability and serviceability of the component.

Section 2

Covers components which interact directly with the wheelchair user. This section focuses on factors which affect the posture and pressure management of the wheelchair user. Environmental factors also are taken into account for components which are sensitive to wear from regular use or breakdown from urine as a result of incontinence. Each component of the wheelchair is evaluated in terms of user function, environmental considerations and options of adjustability. A comparative matrix of commonly available component options gives a summary of advantages or drawbacks of different design options, as well as an evaluation of the manufacturability and serviceability of the component.

Section 3

Provides an overview of the types of testing available and best practices related to applying them. This has been divided into three sub-categories: Qualifying Tests, Research and Development Tests and User Evaluation Tests.

Section 4

Provides recommendations for individuals, service providers and/or governments to select and purchase wheelchairs.

The information in this document should equip the reader with the various tools needed to make informed decisions throughout the various stages of the design process. This will aid engineers and manufacturers to develop appropriate, durable and functional wheelchair designs.

Key Concepts and Definitions

Appropriate Wheelchair

An "appropriate wheelchair" as defined by WHO is a wheelchair that:

- Meets the user's needs and environmental conditions
- Provides proper fit and postural support
- Is safe and durable
- Is available in the country
- Can be obtained and maintained and services sustained in the country at the most economical and affordable price.

Adverse Conditions

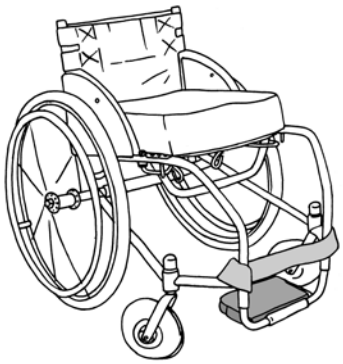
Adverse conditions is a term used to suggest an environment that is unusually harsh on a wheelchair and/or difficult to propel a wheelchair in. Conditions that can be determined as adverse include, but are not limited to:

- Excessive moisture/rainfall
- Excessive heat
- Rough terrain such as soft dirt, gravel, uneven ground, holes, obstacles
- Long-distance propulsion required by the user
- Reduced access to service and parts.

Other terms often used to denote wheelchairs for adverse conditions are Less Resourced Environments (LREs) or Less Resourced Settings.

Basic Wheelchair Users

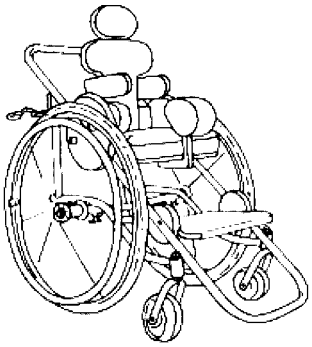
The WHO Basic Wheelchair Service Training Package defines Basic Wheelchair users as those who are able to sit upright without additional postural support.

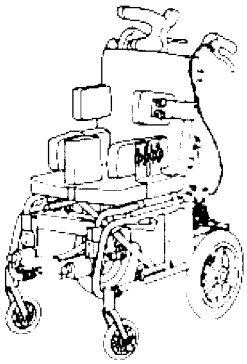


Intermediate Wheelchair Users

The WHO Intermediate Wheelchair Service Training Package defines Intermediate Wheelchair users as those with poor postural control who need additional support.

In addition to typical basic wheelchair components, the intermediate wheelchair accepts PSDs and may accommodate depth growth.





Design Influencers for Wheelchair Users

A wheelchair interacts with and is affected by both the environment and the user. An appropriate wheelchair should be well matched to both of these elements. As such, a well-designed wheelchair should be durable and versatile enough to cope with the user's environment and lifestyle; keeping in mind that the wheelchair should not only help the user perform daily activities but also should support the user's posture without having a negative effect on health and safety.

Needs of the User

Wheelchair design requires that designers initially determine who they are designing the wheelchair for. Wheelchairs for permanent use are not generic devices that can be utilized by anyone needing a wheelchair.

Wheelchair users vary by:

- Size
- Age
- Postural requirements and the need for PSDs
- Functional needs
- Ability to propel the wheelchair independently
- Geographical or home environment
- Changing needs (e.g., children who are growing)

Further, wheelchair designers have to decide which specific user group they are designing for. Examples include: Elderly low-activity users; active users with good upper body strength; pediatric cerebral palsy users with more complex postural needs; users who primarily use the product outdoors in rough, uneven terrain and cover long distances; and users who live in very hot or very moist climates where corrosion of parts or decaying of fabric are constant problems. Additionally, as a designer, you may decide that you are going to produce the lowest cost wheelchair possible, manufacture it in high volume and not worry whether it is designed for a specific user group. Either way, it is important for designers to understand the intent of wheelchair design before they begin. Last, the design should take into account the ability to source and pay for replacement parts so that the user may benefit from the device for as long as possible. Users in LREs often abandon their wheelchairs early in their use due to breakage or poor fit.

Environmental Considerations

Designers should account for the effects that different environments can have on the design. Below are some environmental considerations.

- Design considerations related to usability of the wheelchair in different environments:
  - Rough terrain can affect the usability of the wheelchair for users with weak upper extremities.
  - Tight or small living spaces can affect the maneuverability of the wheelchair.
- Implications on reliability related to the environment:
  - Cold weather can cause plastic parts to fracture prematurely.
  - Rough, uneven terrain accelerates breakage.
  - Heat and light can fade colors and break down fabrics and rubber.
  - Moisture can corrode parts quickly and speed up the decay of tires and casters, as well as foam and upholstery.
- Constraints to access to replacement parts (wheels, tires, casters, upholstery, etc.) in the area.

Regardless of which design path you choose, make sure you define your goal and intent in producing a wheelchair for adverse conditions.

***Note:** Talk to the people who will be using your product, enlisting their knowledge and ideas.*

Ergonomic Considerations

A well-designed wheelchair should help the user perform his/her daily tasks and functional activities without negatively impacting health or safety. The functional requirements of a wheelchair vary depending on the user's functional abilities, environment and goals. For a wheelchair user who is predominantly indoors, having a wheelchair which can comfortably fit under a desk or table can give him/her the opportunity to make use of existing furniture. Users who use transport to travel to work (or to school) by car or public services may prefer the convenience of folding or collapsing their wheelchair for easy transport. A user in a rural setting may prefer to have a three-wheeler with larger wheels to help her/him independently navigate rough terrain. The wheelchair should be designed such that the user can perform as many daily activities as possible, and as easily as possible. An important step in designing a wheelchair is to understand how the chair will be used in all environments applicable to the user.

Transfers

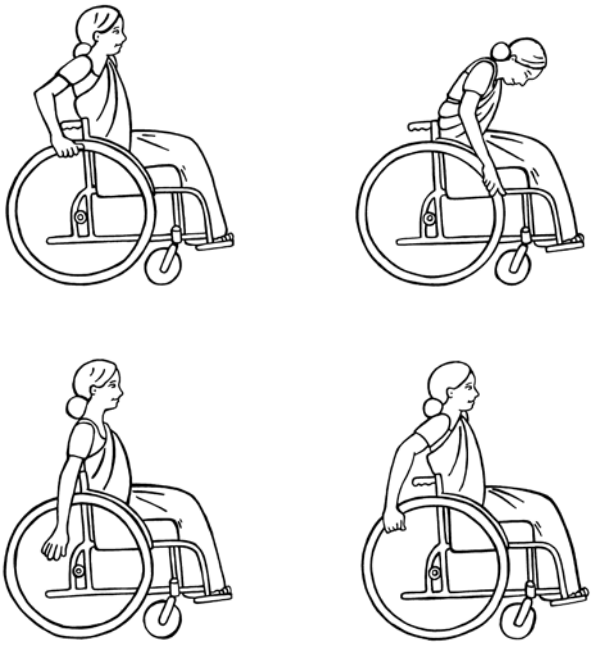
All wheelchair users also need to transfer in and out of their wheelchairs from time to time. Some aspects of the wheelchair are designed specifically to cater for this (see section on armrests). Activities such as transfers or pressure relieving exercises put additional forces on the armrest and possibly footrest, and frequently are a source of component failure. Common ways of transferring out of the wheelchair are sideways, forwards or with the aid of a transfer board, depending on the ability of the wheelchair user.

Overall Dimensions

The width of the wheelchair also is an important factor. A well-fitted wheelchair is vital to function and providing appropriate posture support. Most adult wheelchairs are available in a product range in 2" increments. Just about all wheelchair users are required to bring their device indoors at some point. This is only possible if the widest part of the wheelchair is smaller than the width of a standard door. A shorter overall length improves maneuverability around the home but may decrease stability on rough terrain depending on the design.

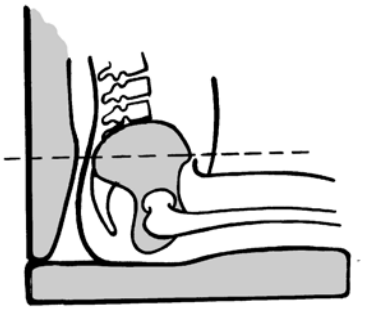
Ability to Self-Propel

Not all wheelchair users have the ability to self-propel, and even those who self-propel may need assistance. It is, therefore, important to ensure that wheelchairs have push-handles which are located at a decent height to ensure easy handling. This additionally affects the stresses experienced by the wheelchair frame and puts additional strain on the back-posts.



Posture Support

It is important to note that an appropriate wheelchair is required to give a proper fit and posture support. A healthy posture ensures that the wheelchair user can maintain his/her level of ability and can prevent the development of life-threatening pressure sores and other secondary health complications. For this reason, details of the effects which different wheelchair elements have on posture form a fundamental part of this document.



Section 1

Wheelchair Components

Frame

Design Overview

The wheelchair frame is the centerpiece of the product, and multiple factors that can affect the usability of the product for people with a wide variety of needs have to be taken into consideration. What feature is most important for a particular user group may take precedence over other features. For instance, the need to transport the wheelchair may be more important to some users than stability. The first step in designing a wheelchair is to understand how the chair will be used and in what environment it will be used. Make a strong effort to understand the needs of the population you will be designing for. Don't make assumptions. Seek input from the people who will be using the product. Once you have heard all the user voices, prioritize their wants into a wheelchair specification taking into account those features that may have a negative relationship. For instance, a user may ask for a super lightweight and very durable wheelchair, and those two wants may be difficult to achieve in the same wheelchair design. It is not impossible, but they may be in conflict with each other.

A modular wheelchair design may offer the possibility of achieving multiple goals but also may lead to a costly design or compromises in the design which pleases no one. Again, not impossible but can cause conflict in the design and result in poor design. Some manufacturers have tried using consumer products for wheelchair seats. These can be low cost and easily sourced but often do not have the seating ergonomics (proper seat angle, length, back height or angle, cushioning, etc.) required by wheelchair users or the durability required. This need for configuration options and dimensions is

precisely why so many variations of wheelchairs exist in the world today for users with complex needs. No one chair is right for every wheelchair user. **Understand who you are designing the chair for.**

Frame designs for basic wheelchair users can be categorized in several categories:

- Folding frame
- Rigid frame
- Four-wheeler
- Three-wheeler
- Trike (propelled by hand crank)
- Motorized wheelchair

Function

Users select wheelchairs based on their ability to provide independence and function as fully as possible in their everyday lives. Those choices can be affected by ability level, training, support by caregiver, work, school, home environment, weather, or social constraints placed on people with disabilities. Factors affecting their choices can include:

Transportability

Rigid frame wheelchairs (non-folding frames) often are designed so the back folds down onto the seat and with quick-release rear wheels to reduce the overall size for transport. Folding frame wheelchairs typically are built with cross-braces to allow the chair to fold up and may make it easier to store or transport. Even folding chairs, however, may be too large to fit into a small space.

Inability to Propel Using a Rear Wheel (Trike or Motorized)

Users who are unable to propel a wheelchair via the traditional rear wheel or who have to cover large distances each day may use a Trike with a hand crank or even a motorized wheelchair.

Supportive Seating (for Intermediate Wheelchair Users)

Wheelchairs can be designed in ways that are easier to attach supportive seating, including padded solid backs and seats. This often includes back canes and seat rails that have tubing diameters consistent with wheelchair seating hardware and do not have interferences or inhibit folding.

Seat Angle

Wheelchair frames often are designed with 4-5 degrees of seat angle relative to the floor. This helps prevent users from sliding forward in the chair and losing stability. Some wheelchairs are designed with a steeper angle to improve stability even more. That can, however, result in it being more difficult for a user to transfer in and out of the wheelchair.

Seat Height

The height from the floor to the seat in the design of a wheelchair can have an effect on the user's ability to propel the wheelchair utilizing his feet as well as his arms. In addition, the seat to floor height can make a difference in how easy or difficult it is to transfer in and out of the wheelchair.

Environmental and Resource Constraints

The user's environment can greatly affect the choice or design of a particular wheelchair. What may work in one environment can be inappropriate for another environment. Environmental concerns to take into account should include:

Tall Curbs

Having to negotiate curb heights greater than those in resourced countries may require a longer wheelbase chair or one designed so that the footrests are permanent to the frame and located above the casters to avoid having the footrests make contact with the ground when descending a curb. Wheelchair users who are able to descend curbs in a "wheelie" position are able to avoid this, but that often is not possible when curbs are 6" high or the user does not have the appropriate strength or wheelchair skills.

Uneven Ground

Having to propel a wheelchair long distances over uneven ground can lead a user to choose a longer wheelbase chair for stability and can decrease the weight on the front casters.

Small Homes

Users who need to use their wheelchair inside their home and reside in a small home may choose a wheelchair with a shorter wheelbase for improved maneuverability, sacrificing the outdoor stability.

Spare Parts

If wheelchair replacement parts are not easily accessible to the user, he/she may choose to purchase a wheelchair where parts are available locally, such as bicycle size wheels, tires and tubes and locally sourced wheel and caster bearings.

***Note:** Unfortunately, no matter how you design the product, many users will not have the means to pay for even minor replacement parts or maintenance.*

Adjustability

Frames can have adjustable center of gravity settings to improve user access to the rear wheel for optimal ergonomics, as well as seat to floor height options. Adjustability may include backrest height and/or seat width or depth dimensions to fit different sizes or growth for children. Adjustability can lead to increased design complexity and additional cost but may be necessary in order to be considered appropriate for active wheelchair users or those with complex physical disabilities.

Rear Wheel Placement and Adjustability

Some wheelchairs are designed with multiple hole locations for the rear wheel in the vertical and horizontal planes. Being able to attach the wheel in multiple locations in the vertical plane can raise the seat to floor height for taller users. It also can serve to raise or lower the rear wheel relative to the user's shoulder. Being able to attach the rear wheel in multiple locations in the horizontal plane can change the center of gravity of the wheelchair but also is useful for improving the wheel position relative to the user's shoulder.

For wheelchair users who are active and propel their wheelchair frequently during the day or over long distances, it is necessary to make sure the rear wheel is in a location that allows for good ergonomics between the wheel and the user's arms. If the wheel is located too far backwards on the frame, and the user has to reach too far rearward to achieve a solid grip on the wheel, it may cause additional force on the user's shoulder, resulting in a repetitive shoulder injury. This also is critical for weaker users who are already disadvantaged by weakness. Poor ergonomics further disadvantage them biomechanically. This can make the difference between self-propelling and being dependent for some users.

For users whose body mass is located further back (users with amputations, pregnant women, men who are tall and broad shouldered, etc.), if the wheel is too far forward, it can cause a poor center of gravity and make the wheelchair tippy in the rearward direction. To reduce strain on the shoulder and improve shoulder biomechanics, the user often will lean forward, resulting in postural deviations occurring over time.

It is important for the designer to find an ideal location for the COG of a wheelchair to yield a suitable combination of functional properties. Although having an adjustable COG is recommended for superior versatility, this is not a requirement for all wheelchairs, especially if the design has a fixed tilt and seat-to-back angle. Nevertheless, the COG will need to be well situated to yield a successful design.

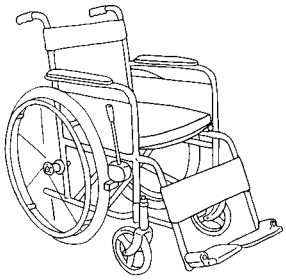
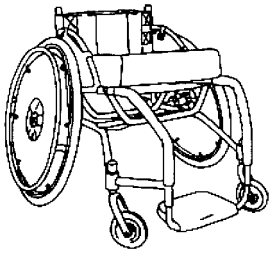
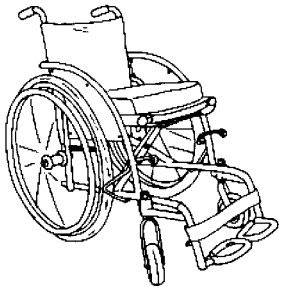
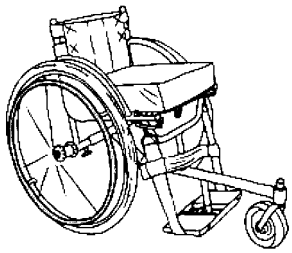
Growth

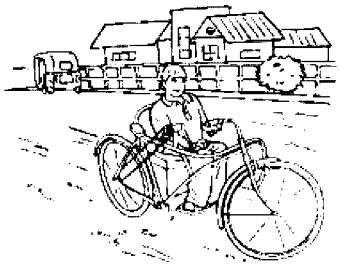
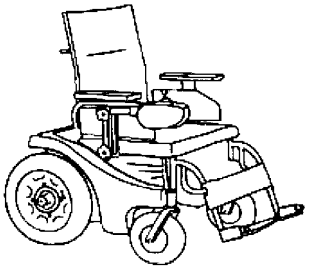
Wheelchairs specifically designed for children may be quite different than adult wheelchairs. One of the key differentiators is the ability for the wheelchair to grow in width and/or length. Typically, many children with disabilities such as Cerebral Palsy have a greater tendency to grow taller than wider, so it usually is most critical for pediatric wheelchairs to grow several inches in length. This is not universally true, however, as other children such as those with spina bifida can grow in width and weight. Flexibility allows the chair to be useful to the child for a longer period of time. For children who self-propel, having the appropriate width chair and the ability to increase the width is important. If the wheelchair is not of the appropriate width for the child, he will have trouble reaching the wheels, resulting in reduced independence.

Rigid Frame vs. Folding Frame

Two commonly used frame styles can be categorized as the Rigid Frame and Folding Frame. The folding frame consists of two side frames connected by a hinged cross-brace. Each side frame rigidly connects the rear wheel hub, front wheel hub, seat tube, and, occasionally, the back canes and armrests. This design has the advantage of folding flat for ease of transport. Rigid Frame wheelchairs have a base weldment with all four-wheel hubs rigidly connected. The seat and/or back canes are either hinged or rigidly connected. Frequently, the push handles of Rigid Frame chairs are able to fold flat, and the wheels are easily removable for ease of transport. A rigid base also forms a firm surface which lends itself to the integration of features such as adjustable tilt, adjustable back to seat angle and rear wheel chamber. Further details of the advantages and disadvantages of each of these systems are illustrated in the matrix on the following page.

Frame Style

Frame Style	Advantages	Disadvantages	Design Recommendations
Folding Frame 	• Folds compactly for storage or transport in a car, taxi or bus. • Wheelchair flexes which can absorb vibration on harder or uneven surfaces.	• Cross braces and hardware can corrode or break. • Chair flexes when pushed which can make the chair harder to propel. Loss of propulsion energy and more fatigue.	• The cross-brace axle bolt often is designed to allow movement of each side of the frame. • A reliable jig should be used to manufacture cross brace. • The pivot point of the cross braces should be reinforced to resist fracturing.
Rigid Frame 	• Can be easier to propel due to lack of flex in frame. • Frame is robust. • Easy to integrate features such as tilt and recline. • Can easily integrate rear-wheel chamber.	• Frame does not fold for transport, although typically, the back folds down to reduce overall height for transport and may have quick-release rear wheels.	• Can be slightly less complicated to manufacture due to fewer parts; however, higher tolerance in production may be required in order to get all four wheels to touch the ground simultaneously. • Easier to modify for postural support accessories. • Can be very difficult for transport in LREs. • Three-wheelers often are rigid because of challenge to develop folding system.
Four-Wheel Frame 	• Shorter wheelbase than many three-wheelers so better maneuverability. • Often more stable in the lateral direction, but depends on wheel base length.	• Less stable forward than a three-wheeler due to shorter wheelbase. **Note:** *Forward tipping is a significant source of injury in wheelchair users.* • Often requires small front casters or foot supports for foot clearance, which can increase rolling resistance in soft terrain and reduce forward stability.	• Easier to accommodate someone who does a stand and pivot transfer. • Socially accepted as a wheelchair.
Three-Wheel Frame 	• A long wheelbase three-wheeler with a large caster wheel makes it easy to traverse uneven or bumpy terrain. • A long wheelbase three-wheeler is stable in the forward direction.	• More difficult to maneuver indoors for long wheelbase three-wheeler. • Can be harder to transfer in and out of the chair if front cantilever is significantly higher than the foot plate, or if the cantilever is an obstacle.	• Lateral stability is highly sensitive to track length. • Often easier to design to track straight compared to four-wheelers.

Frame Style	Advantages	Disadvantages	Design Recommendations
Trike The wheelchair is propelled by a set of hand cranks that drives a bicycle chain propelling the wheelchair. Usually a three-wheel design has baskets for carrying larger items. A trike design can also be accomplished by an attachment to a wheelchair that can be removed when not needed. 	• Better ergonomics (hand crank) for covering longer distances. • Longer wheelbase is more stable on rough terrain. • Larger front wheel handles uneven terrain, mud, gravel and sand. • Can help with cargo transport. • Can use up to 100% of locally available bike parts, making them fully repairable with local resources.	• Not usable in small spaces. • Chain drive requires maintenance. • Lateral stability can be poor due to high COG and short track length.	• Trike users must have good upper body strength to propel. • Consider using only locally available materials in design. • Should be designed to accommodate pressure relief cushion.
Motorized Wheelchair A wheelchair frame driven by motors and gearboxes. Movement and steering are typically accomplished through a joystick attached to the armrest. Requires large marine-style batteries. 	• Provides mobility for users with limited arm and finger abilities who experience fatigue with self-propelling wheelchairs and who need to travel long distances on challenging terrain which significantly slows them down or causes undue fatigue with self-propelling wheelchairs.	• Difficult to transport. • Replacement parts are difficult to find.	• More costly and difficult to manufacture and replace components. • Requires electronics expertise. • Requires electricity to recharge the batteries each night. • Maintenance should be major consideration. • More complex to design than manual wheelchairs.

Back Canes

Wheelchairs can be designed so that the back canes are an integral part of the side frame. This can be low cost and appropriate for many users. However, for users requiring the chair to be fitted optimally for them, some wheelchairs are designed with back canes that adjust in height and are attached to the side frame by being inserted into a socket bolted to the side frame. This allows different height back canes to be used or canes that can adjust in height to fit the user. Having a back that is too tall for a user can result in upper trunk movement being restricted. The position of the back canes also will have great influence on the extent the user will gain support from the attendant if needed. If the canes are too low — forcing the attendant to stoop — or they do not provide the leverage needed to overcome obstacles, the user may face limited support from the attendant.

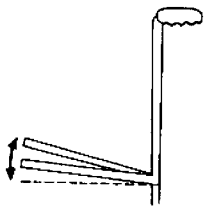
Back canes for wheelchairs which are intended to provide support up to the thoracic spine or the top of shoulders usually have a slight bend in the push handle of around 9 degrees, located mid-way up the post. This bend accommodates for the natural curvature of the thoracic spine once the backrest is mounted. For wheelchairs which are intended for users requiring less back support, the canes should be straight.

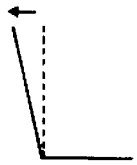
Back to Seat Angle

Back to Seat Angle is defined as the angle between the seat and the base of the backrest. Most standard wheelchairs have a back to seat angle at around 90 degrees. Some wheelchairs have an adjustable back to seat angle. Users who have flexed trunk/spine postures, forward head postures or limited hip range sometimes require the back to seat angle to be adjusted to an angle greater than 90 degrees. Active users with good balance and trunk control may only need support at the pelvis and lower trunk and may use a backrest with a 90-degree seat to back angle which extends to the bottom of their ribcage or sometimes use a short backrest with a back to seat angle of less than 90 degrees (less common).

Wheelchairs with an adjustable back to seat angle hinged at the base of the back canes usually feature back canes which are connected with a cross bar either at the base or at the top of the back canes. This can interfere with folding, and for this reason, standard folding frame wheelchairs usually have a fixed back to seat angle.

Frame Components

Frame Components	Advantages	Disadvantages	Design Recommendations
Seat Base Angle This is the angle of seat base relative to floor. Positive angle results in the back of the seat lower than the front. 	For a zero degree angle: • Easy transfers. • Higher seat height. • Good for foot propellers. For angles greater than zero degrees: • Reduces sliding.	For a zero degree angle: • Leads to sliding out of chair. • Reduced rear-wheel access. For angles greater than zero degrees: • Makes it more difficult to propel by foot. • Makes it more difficult to transfer in/out of chair.	• Often wheelchairs are designed with a 4-degree seat angle.

Frame Components	Advantages	Disadvantages	Design Recommendations
Back Cane Attachment Back canes are welded or bolt-on. The bolt-on type can be of fixed height or adjustable.	Welded: • Reduced hardware. Bolt-on: • Fixed height. • Adjustable - Allows the chair to be more accurately fit to the user's body dimensions and his/her activities.	Welded: • Prone to fail at bottom of the cane. Bolt-on: • Fixed height - Cannot accommodate different users. • Adjustable - Requires different dimensions for the outer diameter of the tubes, making it harder at times to attach support seating bracketry. • Requires extra length in the back upholstery to accommodate the varying heights or requires new upholstery when changing the back heights. • Increased weight and cost of the wheelchair. • Added maintenance.	• Should reinforce welded cane to reduce risk of failure. • Adjustable canes are an easy way to accommodate a wide range of users. • An improper cane height can limit activity and trunk range of motion. (See backrest section for more details.)
Back Angle Back angle can be fixed or adjustable. 	Fixed back angle: • Easier to design. Adjustable back angle: • Improve postural stability and balance by moving the person's center of gravity rearward. • Assist with alignment of the head and neck and improve head control. • Accommodate fixed non-neutral postures of the trunk, pelvis and head and neck. • Accommodate bilateral limited hip flexion. • Accommodate forward folding backrest function.	Fixed back angle: • Does not accommodate needs of wide range of users. Adjustable back angle: • Added maintenance requirements. • Adds weight.	• Opening up the seat to back angle too far can cause the user to slide and increase shear forces at the seat. • Usually requires a maximum of 20 degrees of range which is 5 degrees forward and 15 degrees rearward. • As back-cane is taller, then back angle should be increased to reduce risk of pushing user's trunk forward. • Use of adjustable tension back upholstery can allow users to be individually fit and accomplish some angle adjustment. (See more detail in back-upholstery section.)
Variable Recline Reclining wheelchairs are designed to allow significant changes in the seat to back angle greater than a back angle adjustment bracket. These wheelchairs can provide recline adjustment greater than 30 degrees up to 140 degrees.	• Used to accommodate users with advanced postural support needs, such as pressure relief, repositioning for activities of daily living, etc.	• When the user is returned to the upright position, his/her seating posture is significantly changed and requires the caregiver to assist in repositioning. • Variable recline causes shear and increased pressure sore risk. • Inappropriate recline can cause the user to slide. • Adds weight to the frame of the wheelchair. • Harder to transport. • Added maintenance requirement. • Added cost and complexity. • Typically reduced stability in reclined position.	• Requires a headrest extension to be designed and added as well. • Useful for users who struggle with dizziness or breathing problems. • Appropriate pelvis support is required including a pre-seat bone shelf and pelvis strap. • Often requires anti-tippers to limit stability. • Typically requires a longer wheelchair.

Rear Wheel Attachment and Function

Design Overview

When designing the frame and determining how the rear wheels attach to the frame, careful consideration should be taken related to the following factors:

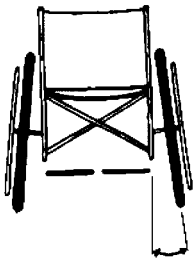
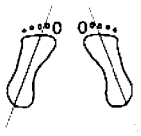
- Camber can improve stability but also can hinder access through narrow doorways.
- Toe-in of greater than 10mm or toe-out of greater than 0mm can severely hinder rollability.

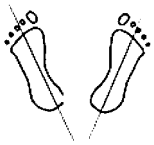
Care needs to be taken as to how the wheel is attached to the frame via a fixed position or adjustable position (vertical and/or horizontal adjustment) to avoid movement that would lead to toe-in or toe-out.

An adjustable position axle can allow the wheel to be placed in an optimal position for the user that takes into account:

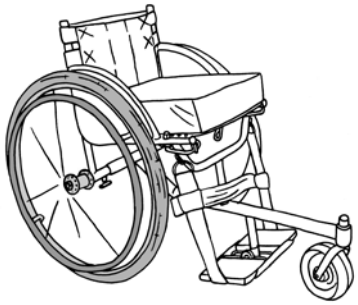
- Stability of the chair (how tippy the wheelchair is).
- Optimal shoulder position for the user to maximize propulsion [4].
- Access to the wheels (the user does not have to reach out or backwards to push the wheel).

Rear Wheel Attachment Feature/Consideration

Feature/Consideration	Advantages	Disadvantages	Design Recommendations
Camber Camber describes the inward or outward tilting of a wheel in the vertical plane. Typically, camber is designed so that the top of the wheels are angled in towards the user. 	• Improves stability. • Improves access to the wheels for propulsion. • Improves wheelchair turning. • Increases propulsion force. • Helps protect hands from impact on door frames.	• Widens the overall width of the wheelchair, limiting access to rooms with narrow doorways.	• 0 degrees or 3 degrees is the most common and does not typically restrict access to narrow doors. • Higher degrees of camber up to 12 degrees or 15 degrees typically are reserved for sports wheelchairs.
Toe-in Toe-in is a feature when the distance between the front end of the wheels is less than between the rear end of the wheels. 	None	• Toe-in of more than 10mm (5mm per side) increases the rolling resistance of the wheelchair.	• Designers should consider adding 5mm of toe-in to their design since toe-out occurs naturally at higher speeds.

Feature/Consideration	Advantages	Disadvantages	Design Recommendations
Toe-out Toe-out is a feature when the distance between the front end of the wheels is greater than between the rear end of the wheels. 	None	• Any toe-out (greater than zero) can increase the rolling resistance of the wheelchair.	• Toe-out occurs naturally at higher speeds.
Horizontal Wheel Location Multiple hole locations are placed on the frame typically to allow the rear wheel to be placed along a horizontal plane over a 3-4 inch span. Can be accomplished with multiple axle hole locations in the frame or a bolt-on axle plate that can be moved. 	• Can improve rear wheel access for easier propulsion. • Allows adjustment to change rearward/forward stability.	• This is not an issue for horizontal movement but does require that wheel locks are movable.	• Shifts in horizontal axle position in the horizontal position impacts several aspects of the wheelchair and user. • It can allow more/less access to the push rims. • It can reduce/increase stability of the wheelchair. • It can reduce/increase lateral drift of the wheelchair while on a cross-slope.
Vertical Wheel Location Vertical locations are changed to achieve different seat to floor heights.	• Allows the rear wheel to be moved vertically to adjust seat angle and seat to floor height.	• Adds design complexity. • Requires adjustable casters to ensure caster stem remains vertical.	• Similar to horizontal changes, vertical changes in the rear axle location impact wheel location relative to the user. Sometimes that is the goal of changing wheel location, but sometimes can be a trade-off. • 3-inch vertical height adjustment is not uncommon.

Rear Wheels and Tires



Design Overview

A wheelchair designer may want to decide on the size of the rear wheel prior to designing the frame as this can determine overall seat to floor heights that may or may not have to be accommodated in the frame design. Some manufacturers choose to use 26" spoked rear wheels as they commonly are used on bicycles, therefore easier to source and replace.

24" rear wheels are sometimes less expensive and easier for manufacturers to source in volume due to many wheelchairs being manufactured with this size rear wheel.

Rear wheel selections available typically are:

- 26" spoke wheels
- 24" spoke wheels
- 24" composite wheels
- 12" composite wheels (for dependent users)
- 16, 18, 20 and 22" wheels also are available and sometimes used with pediatric wheelchairs but are lower volume

Rear tire selections available include:

- Pneumatic
- Solid urethane
- Pneumatic tires with foam-filled inserts

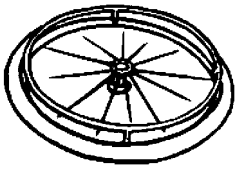
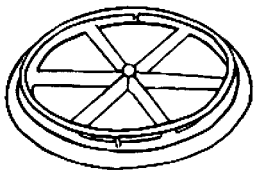
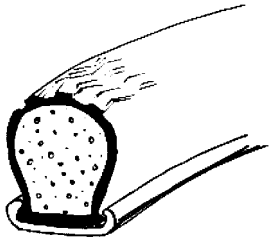
Environmental Considerations

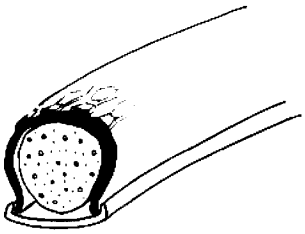
Rear wheels and especially tires are a common cause of wheelchair abandonment if the wheels break or the tires go flat and are not able to be replaced or repaired. Wheelchair pneumatic tires tend to lose air easily because of the small volume of air in the tire, and they can easily go flat from debris and can wear quickly if a user is active.

Serious consideration needs to take place regarding:

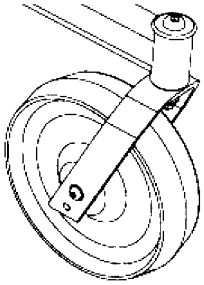
- User's environment including surfaces such as gravel, brick, broken asphalt, soft dirt, etc.
- Availability of replacement parts and knowledge on how to replace the part.

Rear Wheels and Tires Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
26" Spoke Wheels 	• Common to bicycles so often easier for users to find replacements. • May be easier to push on rough terrain. • Good for tall users.	• Spoke wheels can be easily bent or broken. • The 26" diameter can increase the seat to floor heights. • May make it difficult to access tables/desks. • May make transfers more difficult if significant difference in height.	• This larger diameter wheel may make it more difficult for shorter users to access the wheels without compensation in the frame due to the top of the wheel being high relative to the user's seat, forcing the user's shoulder higher when reaching the wheel and creating more stress on the shoulder joint.
24" Spoke Wheels	• Easily sourced by the manufacturer.	• Spoke wheels can be easily bent or broken. • May be more difficult to source in less-resourced settings.	• Ergonomically good for typical body sizes. • It allows user to roll under table, easily access push-rim, etc. This is recommended for high-volume wheelchairs.
24" Composite Wheels 	• Common in wheelchairs produced in mass volume so easy to source for large manufacturers. • More durable traditionally than spoke wheels as they do not go "out of round."	• Harder to replace for consumers due to lack of availability in LREs. • Wheel failure almost always requires replacement rather than repair.	• Have to be sourced from high volume manufacturers and cannot be made locally.
Pneumatic Tires	• Soft ride. • Can be easily sourced from bicycle shops if common size. • Tread pattern offers good gripping power on dirt or moist ground. • Light. • Can have low-rolling resistance when fully inflated.	• Lose air, making propulsion difficult. • Susceptible to punctures, causing flat tires.	• If pneumatic tires are used, the wheelchair user should be trained to repair them, and a pump should be included. • Thicker tubes often can be sourced and can increase reliability of pneumatic tire/tubes.
Solid Urethane Tires 	• Do not go flat. • Can wear better than pneumatics.	• Harder ride than pneumatics. • Typically thinner profiles often than pneumatics so more difficult to grip. • Often minimal tread pattern reduces traction.	• Often fail on standard durability tests due to heat absorption.

Type/Specification	Advantages	Disadvantages	Design Recommendations
Urethane Tire Inserts 	• Can mimic pneumatic tires in width and tread pattern. • Do not go flat. • Typically softer ride than solid tire.	• Often are soft and compress, which increases rolling resistance. • More expensive.	• Costs up front are higher, but lifecycle costs are likely lower due to increased reliability.

Caster Assembly



Design Overview

Factors to consider when choosing a caster wheel include obstacle handling, rolling resistance, foot interference and flutter. Poor selection of front casters or poor design of caster forks and stem bolts can quickly render an otherwise fine wheelchair useless within a very short time period. The caster, fork and stem bolt combination takes the brunt of the force applied to a wheelchair when hitting obstacles and traversing rough terrain. Casters can cause poor rollability issues and make it very difficult for users to propel their wheelchair. In adverse conditions, you typically find failures including casters that decay rapidly from the extreme heat and moisture, bent forks and rusted caster bearings or stem bolts. Front caster wheel sizes most often are tall and narrow for mass produced and indoor or institutional wheelchairs. Casters designed for wheelchairs in adverse conditions come in a variety of sizes and configurations but typically are wider than the basic indoor wheelchair caster tire.

Caster tires come in a variety of materials including:

- Solid tire made from polyurethane
- Solid tire made from rubber
- Pneumatic tire with air tube (pneumatic casters lose air very quickly and are not recommended)

Design of caster assemblies include:

- Fork design (strength, adjustability)
- Bearing selection (precision for rollability, moisture resistance, replaceability)
- Wheel diameter and width (rollability, foot interference, obstacle handling, durability)

Environmental Considerations

Casters are the frontline of wheelchairs and are subjected to all kinds of impact, stress and moisture. Environmental factors to consider that can cause failure, impaired ability to propel the wheelchair or difficulty in handling obstacles include:

- Tall curbs or obstacles often are harder to negotiate with smaller casters but can be compensated with proper wheelchair setup and training.
- Uneven and rough ground including cracks, debris, gravel, soft dirt, etc.
- Heavy moisture sometimes combined with extreme heat can cause decay or corrosion.

User Fit

Caster size is a major factor in increasing the chance of footrest interference. This is the reason why standard hospital chairs have an open knee angle to clear the front wheel, which can be the cause of postural issues for full-time wheelchair users. See Footrest section for more information.

Caster Assembly Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Caster Width	Wide (>1.5"): • Tracks well over soft and rugged terrain. • Can pass over gaps, such as subway grates. Narrow (~<1.5"): • Swivels quickly on hard surfaces (with proper profile).	Wide (>1.5"): • Heavier. Narrow (~<1.5"): • Poor tracking over soft and rugged terrain. • Can wear faster.	Choose caster size based on the intended terrain use and user profile.
Caster Diameter	Large (>6"): • Reduced rolling resistance (with all other factors equal). • Leads to higher seat-to-floor height. Small (<6"): • Increased clearance for foot support.	Large (>6"): • Reduces footrest clearance for 4-wheeler. Small (<6"): • Can get stuck in potholes and are unable to go over obstacles and stones.	Choose caster size based on the intended terrain use and user profile.
Tire Materials	Rubber: • More reliable in adverse conditions. Polyurethanes: • Low cost. • Light.	Rubber: • Heavy. • Expensive. Polyurethanes: • Unpredictable quality.	• Poor quality rubber material degrades faster. • Some polyurethane tire perform poorly when exposed to water.
Precision Ground Sealed Bearings	• Widely available. • Easier to maintain. • Easier to find replacement parts.	• High quality variation.	• These are recommended bearings for wheelchairs. • Quality varies significantly based on supplier, so source selection is very important. • 6202 bearings are commonly used in wheelchairs because of how widely available they are worldwide.
Bicycle Front-Wheel Type Bearings	• More clearance between balls and race allow debris to move out of bearing. • Often are strong enough for wheelchair application.	• Requires routine maintenance. • Becoming less widely available.	None
Forks and Stem Bolts		• Strong if proper thickness of fork is used.	• They can corrode easily. Use a corrosion-resistant coating.

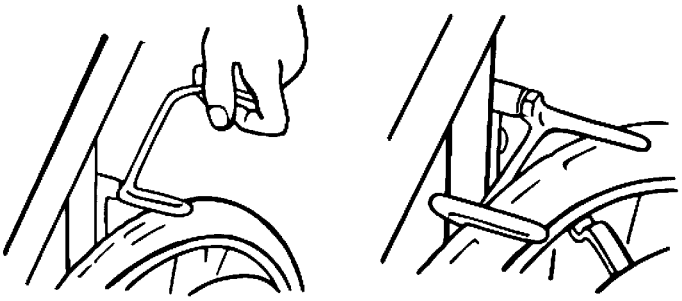
Wheel Locks

Design Overview

Wheel locks are designed to hold the wheelchair in place on small grades up to 9° (traditionally the standard in developed countries). They also are useful for holding the wheelchair still when the user is transferring in and out of the wheelchair. It also is important to note that wheel locks often are the source of regular maintenance issues. They are intricate designs that can easily loosen up or corrode, making them ineffective.

User Function

- It is important that the user be able to reach the wheel locks in order to activate them. Many users have poor trunk balance and cannot lean very far forward. The force required to activate should not be excessive for users but still able to maintain the hold on the wheel.
- Many users have poor hand function, so the wheel locks typically have rubber tips on the handle to make it easier and more tactile on the user's hands.
- Wheel locks should be designed so they do not obstruct propulsion of the wheelchair.
- Wheel locks should not be able to be disengaged by pushing/pulling on wheel.
- For some reclining wheelchairs, tilt in space wheelchairs or pediatric wheelchairs, some wheel locks are mounted on the frame rearwards of the rear tire for easier access by the attendant.
- If the wheel lock loosens over time and rests against the wheel, it can be a cause of wear on the tire.
- Wheel locks should be repairable if they loosen or break. For instance, if a wheel lock is riveted on, it is difficult if not impossible to repair.



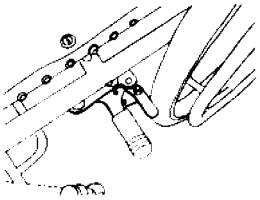
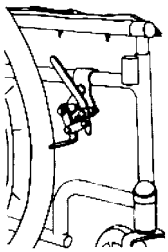
Adjustability

As the rear tires wear, the wheel locks will no longer engage in to the tire when locked. For this reason, some wheel locks are designed to be adjustable fore and aft to account for tire wear or for wheelchairs with adjustable rear axle positions.

Environmental

Wheel locks are exposed to moisture on a regular basis in adverse conditions; therefore, they can corrode and become ineffective. Wheel locks are a high service item so should be designed so that they are easily replaced or repaired.

Wheel Locks Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Undermount Scissors (Lateral) 	• Improved thumb clearance. • Nice aesthetics because it swings.	• Can be difficult for user to reach handle. • Can require a lot of force to activate/deactivate. • Prone to misadjustment.	• Important to design the lock so that it is spring loaded to easily retract underneath the side rail so that it does not impede wheel stroke or injure the user's hand.
Push-Pull 	• Can be easier to user for individuals with more significant functional impairments.	• Can be obstacle during transfers and lead to injuries.	• Important for handle to be out of the way when locked to allow for safe transfer.
Wheel Lock Handle	• The lock handle makes it ergonomic for the user to engage the lock.	• May wear off due to repeated lock engagement. • May corrode sooner in hot and humid environments.	• Important to make sure handle is ergonomic and that plastic handle (if part of the design) does not fall off.

Section 2

Wheelchair-User Interface Components

Seat and Back Upholstery

Design Overview

The wheelchair seat and back upholstery form the basic structure in which the wheelchair user is supported. It is, therefore, important that it is both sturdy enough to allow the user to maintain a healthy posture and soft enough not be a pressure risk.

Note: *Most full-time wheelchairs users are always at risk without a proper wheelchair cushion. Wheelchairs for full-time users should always be delivered with an appropriate cushion.*

Parts of the upholstery interface directly with the wheelchair user and often are subjected to abrasion and wear from performing daily activities. This means that they are high-wear items that can lead to abandonment of the wheelchair when torn, and it can lead to postural instability and pressure problems if it sags too much (hammocks).

The choice of material, sew pattern, and reinforcement near attachment points is critical for the longevity of the wheelchair and for the ability to replace when worn. Issues to be aware of when designing the seat and back upholstery are:

- How long the user spends in the chair each day
- Whether the user independently performs weight shifts (relieves pressure on his/her bottom)
- Replacement needs
- Stretching or sagging of the material
- Moisture
- Cleanability

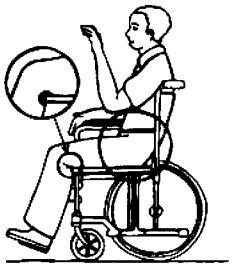
Rigid frame wheelchairs frequently are designed with rigid seat panels (usually made of either plastic or wood). This is generally found to improve the durability of the wheelchair and create a sturdy, durable surface for the cushion, thereby improving the ability of the cushion to give proper postural support.

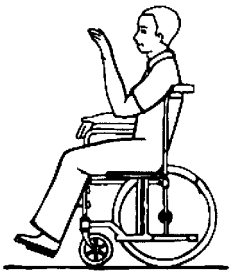
Adjustability

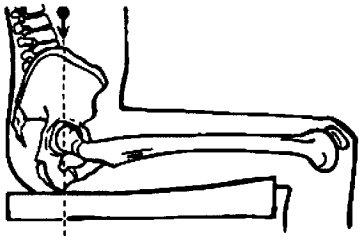
Components of the wheelchair which support the end user are commonly adjusted during the device fitting to fit the user and support his/her posture. Designing elements into the wheelchair can assist with this process and greatly improves the ease of use and the range of users for which the device can be appropriate.

Seat Length

Wheelchair cushions frequently are cut or enlarged to size to properly support the full length of the wheelchair user's thigh while allowing the back of the pelvis to sit up against the backrest. In cases where the cushion is cut to size, the wheelchair seat will need to be adjustable to accommodate this resized cushion. This is commonly and affordably achieved by adjusting the placement of the seat upholstery or even folding the front section of the seat upholstery back to create the shorter seat length. It is important to note that in these cases, the footrest often is required to move back towards the user to maintain the same angle of the knees. An alternative to this would be to adjust the position of the push handles to sit further forward on the seat if the wheelchair has this adjustability feature. This will allow for seat length adjustment without the need for adjusting the upholstery or footrest placement (and mitigates the risk of front caster interference); however, this method greatly alters the COG of the chair and rear-wheel access.

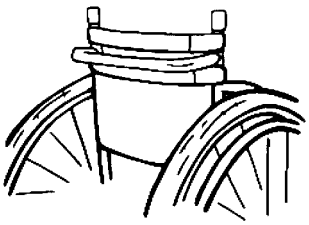


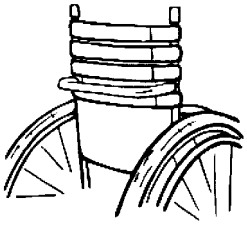




Backrest Height

Many wheelchairs have backrest upholstery which is height adjustable to fit the particular user. This commonly is adjusted in much the same way as adjusting the seat length — where the backrest either is repositioned to the desired height, or excess material is folded back on itself. Excess material can be stowed underneath the wheelchair seat or in some cases underneath the wheelchair cushion. Tension Adjustable Backrests (TABs) usually accommodate this height adjustment by removing straps or folding excess back on itself and then repositioning the backrest cover.

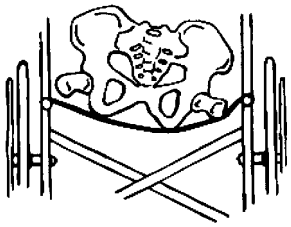




User Function

The wheelchair seat and back upholstery should support the user in a healthy, comfortable posture that provides adequate support to allow optimal function and the ability to use the wheelchair for as long as needed during the day. Excessive sagging of the back and seat upholstery can increase the back to seat angle, creating a more slumped posture. This can create issues with posture support (mentioned below), and create discomfort — which can affect the amount of time the user will feel comfortable and active in his wheelchair. This also shifts the COG of the user backwards and changes the location of the user's shoulder, affecting rear wheel access and, in turn, affects the user's ability to propel efficiently.

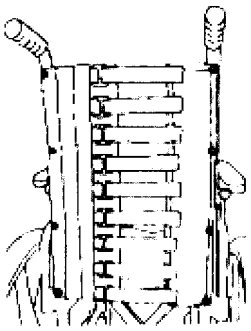
If the wheelchair user is only spending 2 hours a day in his wheelchair or has the ability to transfer in and out of the chair regularly, this becomes less critical. For users with poor postural stability or who spend many hours per day in the wheelchair and are unable to independently weight shift, this is a major area of design consideration, as sagging seat upholstery can increase pressure on the bony prominences due to "hammocking" even with a wheelchair cushion.



Many wheelchair users have issues with incontinence. Urine not only leads to breakdown in the material but also can make the upholstery a breeding ground for bacteria and insects, especially in warmer climates. Ideally, the material should be resistant to harmful effects of urine and moisture and be cleaned easily with soap and water or disinfectant.

Tension Adjustable Backrests (TABs)

TABs are commonly used on wheelchair designs as a more versatile means of giving proper posture support. The upholstery is supported by a number of width adjustable straps. The tension on these straps then can be adjusted to support the user's pelvis and trunk or create a slightly reclined posture. This element is used frequently even on low-cost wheelchair designs as it is an affordable way to accommodate a larger number of users by being able to support a variety of different postures. Another advantage is that some of the slack which develops over time can be compensated for by tightening the straps.



A number of other options are available to create posture support for wheelchair users. These are explored more in depth under PSDs.

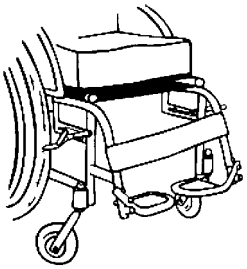
Environmental Conditions

In LREs, wheelchair upholstery often is subjected to high temperatures and excessive moisture. This leads to faster wear and replacement needs. Keep that in mind when choosing material. If foam is used inside the upholstery without proper covering, the foam will break down quickly and can harbor bacteria and odor.

Seat and Back Upholstery Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Natural (Cloth) Material	• Inexpensive. • Easily replaced.	• Tears easily and needs frequent replacement. • Difficult to wipe clean. • Stains easily.	Difficult to design cloth upholstery that doesn't tear easily especially at the attachment point.
Synthetic (polyvinyl chloride commonly known as PVC, nylon, etc.) Material	• Easily cleanable. • Easily sourced. Nylon: • Abrasion resistant. • Can be breathable. Vinyl: • Inexpensive.	Vinyl: • Vinyl is prone stretch (hammock). • Can crack. • Hot.	• The decision between nylon and vinyl is important as vinyl performs worse than nylon. • Anti-stretch webbing materials are needed as part of a composite.
Use of Metal Slats To reinforce where the upholstery is attached to the side rails with seat upholstery screws.	• Reduce the tearing or sagging of the seat upholstery.	• Can rust/break. • Often cut/damaged when seat upholstery shortened. • Often forgotten to be replaced when upholstery changed.	None
Inner Foam Layer	• Increases comfort.	• Can hold moisture and incontinence leading to bacteria and odor.	• Added cost. • If in the seat bottom, can lead people to assume a cushion is not necessary.
Rigid Molded Plastic Consumer Seat	• Inexpensive. • Easily wiped down. • Does not sag.	• Can cause pressure sores if seated directly on the plastic. This is true of upholstery, as well, but plastic seats can have slots in the seats that become pressure points or skin abrasion points. • Back can be too firm. • Seat depth is often not adequate. • Cannot be sized for children creating inability to reach the wheels. • Is brittle and can fracture and cut user. • Does not accommodate PSDs, pressure relief cushions, or other modifications.	• Historically has performed poorly because of high frequency of fracture and does not permit proper seating and positioning for most users.
Tension Adjustable Backrest (TAB)	• Adjustable posture support – improves posture support of pelvis and trunk. • Can be used on a folding frame wheelchair.	• Increased labor to manufacture.	• Standard back upholstery often has a tendency to sag and stretch over time, putting the user into a poor postural position. Tension adjustable upholstery can be readjusted/tightened periodically to maintain appropriate support to keep the back in an optimal position. • Number and width of straps, where they are placed, and the types of buckles has a significant impact on the performance and reliability of these systems.

Lower Extremity Support (Leg Support Tubes and Footplates)



Design Overview

Leg and foot supports are critical elements of the wheelchair design and serve a bigger purpose than simply supporting the leg and foot and can play an integral role in maintaining a healthy posture and pressure distribution. One of the key functions of leg and foot supports is to keep the user's feet off the ground and away from the front casters. It also alleviates the pressure which the user experiences under the thighs and protects the feet from knocking into objects when propelling or performing other daily activities.

Foot supports can be separate — independently supporting each foot — or connected in the form of a single footbox or footplate. A single footbox or footplate supported by two hangers has the advantage of being more resistant to hard knocks from regular use. This, however, can interfere with folding. Some foot supports feature two independent footplates which can be clipped together once unfolded to improve durability and stability.

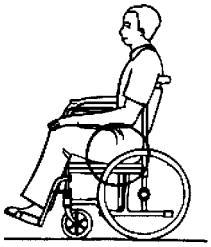
The location of the foot support can be a challenging endeavor for the wheelchair designer. One must ensure that the foot support remains functional at each adjustable setting of the wheelchair while avoiding front caster interference. This becomes particularly challenging when the design has tilt and COG features. When designing wheelchairs intended for outdoor use, it is preferable to have a longer wheelbase to improve wheelchair stability. Having the casters located further forward can increase the risk of caster interference with the foot box. This commonly is mitigated by either placing the front caster/s in front of the foot support or by decreasing the diameter of the front casters such that the foot support can be placed on top of the front casters. These smaller front casters are usually wider than normal to improve durability and prevent them from sticking in soft surfaces.

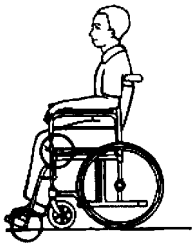
A good rule of thumb: A wheelchair user's lower leg length often is a similar dimension to the seat length. Because of this, the hanger (not foot-support!) of a wheelchair sometimes is placed at an angle. This allows the foot support to sit farther forward when set on a longer setting for users who require a longer seat length.

Postural Support

Properly constructed lower limb supports — when properly adjusted — can enhance postural stability. When adjusted to the right length, the thigh is level to the seat, reducing the pressure on the thighs and ischial tuberosities (ITs). If the leg support length is too short for the user, the thigh is angled upwards, increasing the pressure on the bony prominences.

If the leg support is too long, it may cause the user to slide forward in the chair into a posterior pelvic posture, resulting in loss of pelvic stability, leading to a loss of function including a reduced ability to self-propel. Some wheelchair users' feet are fixed in non-neutral postures. In these cases, having the option of angle adjustment can help either to accommodate or correct the deviation.





User Function

Swing-away and/or removable leg supports can make it easier for a user to transfer in and out of the wheelchair. When the leg supports are moved out from underneath the feet, the user is able to place his or her feet directly on the floor, providing a stable platform to execute a transfer forwards in or out of the wheelchair. This additionally can help to transport the device by allowing the footrest to be stored separately. A common issue with footrests is that the user's feet fall backwards off the footrest. This then causes the user's feet to interfere with the front casters, which can impede maneuverability and be a serious health hazard. This risk is mitigated by ensuring that the user's feet are properly supported behind the heel, either by means of a heel strap or a shelf.

***Note:** Keep in mind that many wheelchair users in less-resourced settings do not wear shoes. This means that the surface of the footrest needs to be free from hardware or sharp edges which could be a potential pressure risk.*

Environmental Considerations

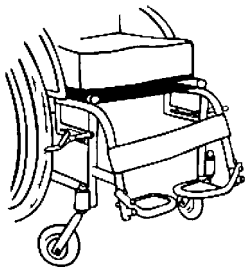
The following are environmental considerations when designing lower limb supports:

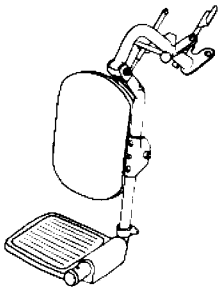
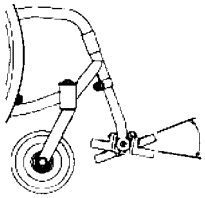
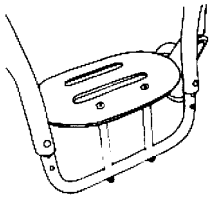
- When descending sharp inclines, the footrests often are the first part of the wheelchair to contact the ground. This can result in the lower limb supports to be bent, broken or worst case cause the chair to tip forward. It is generally considered that there should be a minimum of a 2" ground clearance between the footplate and the ground. This is not always enough, however, in adverse conditions when negotiating tall curbs or sharp street and terrain angles.
- Removable lower limb supports can be lost easily.
- The attachment point between the wheelchair frame and the leg support tubes often is a weak point and susceptible to breakage.

Adjustability

- Because users vary in lower leg length (knee to heel), it is important that the leg support tubes adjust in length. This often is accomplished in wheelchair design by having a slide pivot tube telescope within the leg support hanger and held in place by a bolt.
- The footplates sometimes are designed to be angle adjustable for users with tone or poor range of motion in the ankles and/or hamstrings. This can be adjusted to accommodate or correct deviations.
- Foot hangers sometimes are designed to be angle adjustable. This is done to accommodate users who have fixed knee contractures in flexion or high tone, meaning their knees are fixed at an angle greater than 90 degrees. These footrests usually have additional support on the calf to ensure that the leg is comfortably supported.
- The footplates also are sometimes designed to be depth adjustable to ensure that the user's feet rest securely on the footplate at the correct position. This can be used to maintain a 90-degree angle in the knees once the seat has been adjusted in length or can be an alternative to adjusting angle of the footrest hanger. For this reason, a fore/aft adjustable footrest should be accompanied by an angle adjustment feature.

Lower Extremity Support Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Swing-Away Removable Leg Support	• Aids in user transfers by allowing the user's feet to be placed on the floor directly under the knees. • Allows user to get closer to objects when swung away or removed.	• Can get lost during transportation. More prone to breaking. • Attachment points are prone to failure. • Can add cost to wheelchair. • Often become loose.	• There are many standard components available that can be used as examples or components to use on a new wheelchair design.
Fixed Leg Support	• Do not get lost. • Lower cost of production.	• In the way during transfers.	• Can be designed as bolt-on or part of frame.
Footplate Design • Fixed • Flip-up 	Fixed: • Can be structural member of chairs. • Good mounting surface for psds. Flip-up: • Required for most folding chairs. • Best for stand-pivot transfers.	Fixed: • Makes transfers difficult. • Limits collapsibility. Flip-up: • Are prone to loosen up and go out of adjustment.	Materials selection is important: • Aluminum is durable and resists corrosion. • Plastics are light but prone to breakage. • Both types of footplates can be sourced from wheelchair parts and accessory suppliers.

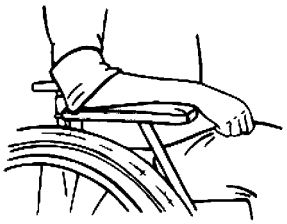
Type/Specification	Advantages	Disadvantages	Design Recommendations
Plastic Footplate	• Light. • Doesn't rust.	• Breakable. • Difficult to replace or source by the user.	• Upfront tooling expense.
Elevated Leg Supports 	• Allows user to elevate the leg if swollen or injured. • Accommodate limited knee flexion postures. • Can be used as a platform to support an amputated limb.	• Can get lost during transportation. • Heavy. • Adds cost to wheelchair.	
Adjustable Angle Footplate 	• Can accommodate non neutral postures of the ankle. • Can integrate angle adjustment mechanism with a fold up feature.	• More prone to coming out of adjustment easily. • Slight cost increase to manufacturability and additional hardware.	• An option on many off-the-shelf designs.
One Piece Foot Support 	• People can use the footboard to transfer in and out of the wheelchair when taught the proper technique. • Can be mounted higher on the leg support tubes for children with short leg lengths. • Can be very durable compared to swing away options.	• In the way for transfers although some are designed with attaching hardware allowing for the footboard to be flipped up out of the way.	• Simple to manufacture. • Can be made out of metal, plastic or even wood if needed.
Adjustable Depth Footplates Can be adjusted fore or aft relative to the edge of the seat upholstery.	• Permits knee angle adjustment. • Help accommodate adjustable seat depth.	• More mechanism in a footplate needed to allow for the adjustment • Can have a tendency to loosen and not stay in place causing continual maintenance problems and having to retighten the mechanism. • Adjusting a footplate backwards in depth can cause it to interfere with caster rotation for four-wheeler. • Leads to change in ankle angle. • Adds significant cost.	• Additional adjustments often do not stay in place and require frequent retightening of the angle adjustment. • Adjustable footrest must never be designed such that it can obstruct casters. • Fore/aft adjustment is often combined with footplate angle adjustment to accommodate ankle changes that occur when shifting position.

Upper Extremity Support (Armrests)

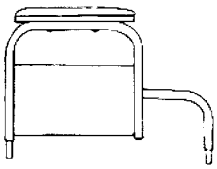
Design Overview

The armrests of a wheelchair are more than a place to "rest" the arms. They can perform multiple functions in addition to resting, including being used for stability, aiding in transfers and attaching wheelchair trays. Not all wheelchair users like armrests so it sometimes can be important to make them removable. Armrests typically have arm pads as part of the design to offer a flat and padded surface to rest the arms. Armrest styles are varied and serve different functions.

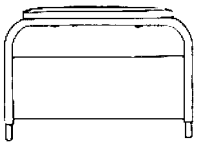
- Fixed or non-removable armrests



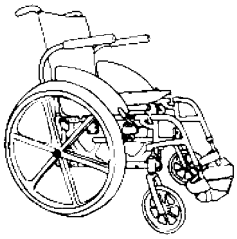
- Removable armrests
- Adjustable height armrests
- Desk length



- Full length arms



- Tubular armrests mounted to the back canes



- Plastic armrest pads
- Padded armrest pads
- Side guards

User Function

People in wheelchairs can use their armrests in multiple ways for functional purposes.

1. Resting the arms when not active in the wheelchair. Here it is important to have the armrests at an appropriate height so that the user does not have to have his/her shoulders in a "scrunched" position to use the armrest. Alternatively, if the armrests are too low, the user may have to lean to one side to use the armrests. Ideally, the user's shoulders should be in a neutral or level position when resting on the armrests. To achieve this, some manufacturers design adjustable height armrests.
2. Armrests can be used for transferring in and out of the wheelchair by users who can perform "stand and pivot" transfers. Conversely, users who transfer from the side of the wheelchair may need to remove one of the armrests to perform that transfer.

3. Many traditional armrests come with Side Guards (also called Clothing Guards) attached. These can be useful for keeping garments out of the wheels when propelling.

Postural Support

Armrests can offer users a means to help them maintain an upright posture. By supporting the weight of the arms, the upper trunk is stabilized, improving posture.

1. When a wheelchair user needs postural support devices (PSD) but does not have access to them, armrests can be the only means to achieve stability in the wheelchair. (Please note that when this happens, the user loses loss of hand function for other activities because the arms and hands are being used for stability to grip onto the armrests).
2. For children or adults who have poor postural stability, wheelchair trays can be added to the armrest, offering postural stability in addition to a place to rest books or food.
3. An important thing to remember is when users are put into wheelchairs that are too wide for them, they will lean to one side to reach the armrest for support, leading to loss of function, discomfort and, in the case of children, postural difficulties.

Environmental Considerations

Armrests — like most of the wheelchair — are exposed in some cases to heavy moisture but also are subjected to heavy wear from the user constantly resting on them. Areas of concern and design include:

1. The upholstery in the arm pads can wear and tear quickly.
2. If the arm pads have foam in the them, once they are exposed to moisture, they will quickly break down.
3. Once the arm pads completely degrade and are removed, the attachment bolts may poke through and become a point of concern for cuts to the skin.

Adjustability

The upper portion of the armrests can be adjustable in height to allow the armrest to be positioned at an appropriate height for the user.

Upper Extremity Support Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Fixed Armrests An integral part of the wheelchair frame structure.	• Inexpensive. • Do not become lost. • Strong enough to be used to lift wheelchair.	• In the way when side transferring. • Not adjustable in height. • Can interfere with the user being able to reach the rear wheels for pushing.	• No major issues. • Fixed armrests are sometimes welded in place to the wheelchair back frame or back canes. This can create a weak spot from heat during the welding process and cause a failure point.
Removable Armrests	• Can be removed to facilitate side transfers, to reduce weight or to be able to more easily reach the rear wheels.	• Often not as strong as fixed armrests. • Can become lost. • Can pull out unsuspectingly when someone lifts wheelchair up by arm support.	None
Flip Back Armrest • Often used on more active wheelchairs and on children's wheelchairs. Tubular armrests attached to the wheelchair back canes.	• Flip back easily to get them out of the way for transferring or activities of daily living. • Often allows for adjust in height along the back cane mounts.	• More intricate design. • Can put stress on the back canes with heavier users. • Restrict the function and increase injury risk for assistant at the back in case of two person transfers.	• More expensive. • May need a locking feature added to keep them from being lifted up when trays are attached.
Armrest Length • Length references how far arm support extends from back support.	Short (desk length): • Easier to get up close to tables to work areas. Long (full length): • More surface to rest arms on. • Can support tray table more easily.	Short (desk length): • Less surface area to rest arms on. Long (full length): • More difficult to get close to tables or work areas.	None
Adjustable Height Arm Support	• Armrests are able to be better adjusted to the individual user.	• More expensive and more moving parts to break.	None

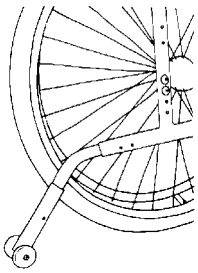
Type/Specification	Advantages	Disadvantages	Design Recommendations
Solid Arm Pads	• Inexpensive. • Can be cleaned.	• Hard surface to rest on (reduced comfort).	None
Padded Arm Pads	• Increase comfort.	• Upholstery tears easily. • Foam breaks down and becomes soiled.	None
Side Guards (Clothing Protectors)	• Keeps clothing from getting caught in the wheels of the wheelchair. • For intermediate wheelchair users, if needed, hip guides or postural supports can be added to the inside of the side guard.	• If removable, can be easily lost.	• Can be difficult to manufacture for small wheelchair manufacturers who do not have access to sophisticated machinery. • They can become bent and bow out and interfere with the rear wheels. • Important to ensure that edge is not sharp as it can injure user during transfer.

Safety Accessories

Design Overview

Wheelchairs most often have accessory options that can improve the safety of the wheelchair. Not every user needs these options, and many choose to remove the options as they gain experience with their wheelchair. These options include, but are not limited to, rear anti-tippers.

Safety Accessories Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Rear Anti-Tippers Designed to prevent the wheelchair from tipping over backwards. 	• When adjusted properly, the rear anti-tippers can prevent the wheelchair from tipping over backwards which may occur when the user goes up an incline, or leans too far backwards. • They can give users confidence to feel safe while learning how to use their wheelchair, such as learning how to perform a wheelie. • Can provide important safety feature for people with poor balance.	• They can add a small amount of weight to the wheelchair. • They can prevent the front casters from lifting far enough off of the ground to negotiate curbs or steep transitions angles. • On uneven terrain, they can catch the ground and high-center the wheelchair which can strand the user.	• Rear anti-tippers need to be designed to be removable either with or without tools so that the user can opt to keep them on or take them off after they become adept at wheelchair skills. • They must be designed so that they are of appropriate length and of appropriate height from the floor to effectively limit the wheelchair from tipping over backwards yet still be able to negotiate small curbs and transitions. • They usually are designed to bolt or snap on to the wheelchair's rear step tubes to allow for adjustment or removal. • A flexible (e.g., spring-loaded) anti-tipper can lessen the impact of the anti-tippers restricting the wheelchair from overcoming obstacles.

Pressure Relief Cushions

Design Overview

"A wheelchair cushion is a very essential part of every wheelchair, for every wheelchair user" (WHO Wheelchair Service Training package — Basic)[2]. Without a proper wheelchair cushion, users with significant physical challenges or immobility can develop pressure sores that can lead to them having to be on bedrest or in worst cases death. Do not underestimate the importance of the wheelchair cushion to the user's function and health. "Preventable secondary conditions (e.g., infections from untreated pressure ulcers) are no longer among the leading causes of death of people with spinal cord injury in high-income countries, but these conditions remain the main causes of death of people with spinal cord injury in low-income countries." The World Health Organization groups wheelchair cushions into three categories: Comfort, Pressure Relief and Positioning. Wheelchair cushions can be categorized into multiple types or intended uses.

- Comfort cushions are intended to provide comfort.
- Pressure relieving cushions are designed to relieve pressure for those users who are at risk of developing pressure sores by relieving pressure and providing posture support.
- Positioning cushions primarily are designed to assist the user in achieving and maintaining optimum postural support with contours and foam densities. Cushions designed primarily for positioning are not designed to achieve optimum pressure relief.

User Function

Wheelchair cushions assist in user function in several ways:

- The cushion improves the comfort level of the user, allowing him to stay in the wheelchair and active for longer periods of time.
- Wheelchair cushions should be designed with a moisture proof cover to protect the cushion (especially foam cushions) from getting wet. When foam gets wet, it will degrade faster, and when it absorbs urine, it holds in odor.

Ideally, cushion cover material will allow for ventilation, but a moisture barrier is more critical. Some space fabrics have a breathability function.

Postural Support

The cushion — when designed with postural contours — improves the user's stability, allowing him to reach further and not have to use his upper extremities for balance.

Environment

- Wheelchair cushions used in adverse conditions can be subjected to more moisture from rain or excess humidity, making the necessity for a moisture-proof cover even more important.
- High heat can cause the user to sweat and increase the heat level between the user and cushion interface. Both heat and moisture are key contributors to pressure ulcers in wheelchair users.

Wheelchair Cushion Designs and Materials Include:

- Open cell cut foam
- Molded closed cell foam
- Air cells
- Gel

Pressure Relief Cushions Type/Specification

Type/Specification	Advantages	Disadvantages	Design Recommendations
Foam Cushion • PU type (not memory foam).	• Inexpensive. • Easy to make. • Comfortable. • Easy to modify/adjust for pressure relief and posture support.	• Breaks down quicker than other materials. • Absorbs moisture. • Holds in odor. • Holds heat.	• Can be simple to manufacture.
Molded Foam	• Does not absorb moisture. • Easier to clean. • Can be molded with smooth transition contours that reduces high pressure zones.	• Can be more expensive. • Difficult/limited ability to modify/adjust for pressure relief and posture support.	• Requires molds.
Air Flotation	• Lightweight. • Adjustable pressure or firmness for different user needs.	• Can fail suddenly, which can lead to pressure injuries. • Can lead to postural instability. • Difficult to maintain.	• Requires tooling to form and assemble cells. • User/caregiver training and insight critical for safe use. • Can be made locally out of pneumatic tire tubes. • Can be easily over-inflated. • Altitude changes can impact pressure.
Non-Air Flotation (such as gel)	• Can conform to the user's body shape. • Gel moves as the user moves to reduce shear.	• Can fail suddenly and catastrophically, which can lead to pressure injuries. • Is much heavier than other cushion designs. • Changes pressure relieving properties in extreme heat or cold (soften or harden). • Difficult/limited ability to modify/adjust for pressure relief and posture support. • Expensive. • Can cause maceration because of lack of ventilation. • Difficult to maintain.	• Requires equipment to mix the gel and encase in compartmentalized casing.

Replacement Parts

No matter how well a wheelchair is designed, if subjected to the elements or used frequently, it will eventually break, corrode or wear in various areas, especially in items such as upholstery, tires and casters. When designing a wheelchair for use in adverse conditions, it is important to think about how replacement parts will be sourced and how much they will cost to replace. Lack of replacement parts can be a major contributor to a user abandoning his or her wheelchair.

Wear or common replacement items can include:

- Seat upholstery
- Rear tires
- Front casters
- Bearings
- Armrest pads

Frequent serviceability items can include:

- Wheel locks being out of adjustment in relationship to the rear wheel or the bolts loosening up
- Footplates come out of alignment and need straightening and the bolts tightened
- Bolts can rust and need to be replaced.

Section 3

Qualifications, Testing and Procurement

Overview

Evaluating the performance of wheelchairs through standardized testing methods is important during the design process, as well as once a wheelchair is in production. During the design process, iterative testing is essential to determine whether the device meets the design specifications, is appropriate for the intended environment(s), and performs desirably for the user and other stakeholders involved in the production, supply and delivery of the device. Once a wheelchair is in production, standardized testing is important to ensure the device is compliant with national regulations and to determine whether manufacturing quality has changed over time.

In this section, we provide an overview of the types of testing available and best practices related to applying them. We describe them in three sub-categories:

1. **Qualifying Tests:** Commonly used to qualify a product for sale in a certain country. Qualifying tests often are prescribed by national or international bodies as a prerequisite before the product can provided. Examples include the Food and Drug Administration (FDA) which requires qualifying tests in the United States of America. In the context of LREs, the WHO Guidelines on the Provision of Manual Wheelchairs in LREs indicates that ISO 7176 should be considered a minimum standard for wheelchairs being provided.

2. **Research & Development Tests:** Used to elicit failures and performance issues in prototype designs so that the design can be improved prior to production. The goal of these tests is to try to subject a prototype to worst-case scenarios to highlight weak links within the design. These tests include user evaluation tests which are used to solicit feedback from users about the design and support verification and modification of the design prior to production.
3. **Testing Principles:** There are several testing principles that are important to keep in mind when designing and performing testing. These best-practices are to help ensure the tests results accurately reflect the performance of the wheelchair, and that they are defensible.

Worst-Case Scenarios

It is important to know the conditions that are related to the worst-case scenario when designing and carrying out tests. For instance, for the safety of the users, tests often are performed to determine whether a wheelchair will fail catastrophically when it is in use. Performing tests under conditions that are average (e.g., average user weight) would only predict whether the wheelchair will be safe for approximately ½ of the population of users; any user who weighs above average could be at risk. Instead, testing conditions should be set to reflect the worst-case scenario. Using the same example as above, the user weight condition should be selected to be the max weight of a user who may use a wheelchair. In conditions where the parameter is normally distributed, a maximum value typically is considered two standard deviations above the mean (mean + 2*SD).

Repeated Trials

There is variability in all tests that are performed which leads to a variation in the testing results. The variability could be from many sources — some known and some unknown. For instance, the welds on a wheelchair frame may not be consistent, which could lead to failures during load testing of one frame but not another. Testing methods also are sometimes difficult to reproduce, which can lead to different test results even with all other variables being fixed. To address this variability, it is important to perform multiple trials and investigate the average and standard deviation of the test result (or another applicable statistical test).

A general rule of thumb is that as the variability increases, so do the required number of repeated trials. Validation testing (e.g., ISO 7176) of wheelchairs is a common test and has limited variability due to the standardized test methods. Best-practice is to perform three repeated trials of each wheelchair to determine the test results. In-home testing with users is an example where there may be wide variability; thus, at least 10 repeated trials may be necessary.

Documented Methods

It is critical to document all testing methods and results. This helps to ensure that the test is defensible when questioned, and that it can be repeated by others if necessary. A general rule of thumb is that all tests must be documented with enough detail that the test can be replicated by someone else. In many cases, documentation such as test reports is required to satisfy regulatory requirements.

Qualifying Tests

The goal of qualifying tests is to demonstrate performance of a wheelchair or related product according to set standards. Examples of qualifying standards are listed below with description of how they are applicable.

Name	Scope
ISO 7176	Covers testing for manual and power wheelchairs and is used as reference for most national standards.
Whirlwind ISO+[7]	Low-cost approach to ISO 7176, with additional tests focused on conditions in LREs.
ISO 16840	Tests for Wheelchair Seating Systems
WC 19	Wheelchair Crash Testing
ISWP Wheelchair Standards	Caster, rolling resistance, corrosion, and whole-wheelchair testing

R&D Tests

When a new wheelchair is designed, an existing design is modified, or new components are designed or modified, it is important to perform tests prior to launching the product. Testing will help to ensure the product is safe and durable for the user. Testing also can provide valuable feedback about design changes that may improve performance.

Notes:

1. All testing performed should be in compliance with local regulations and good practices. In many cases, this may require an ethics board review and approval prior to human subjects testing.
2. Any safety concerns that are found at each of the stages of testing described below should be addressed, and testing should be repeated at that stage to check if the design changes addressed the safety concerns. There are several testing approaches, and we present them in the order in which we recommend they be performed.
   - **In-Lab Qualifying Test:** A first step when evaluating a new design is to perform qualifying tests that are relevant to the strength and durability of the product. This is done prior to any user testing to ensure that there are no obvious failure modes or safety concerns with the product. The appropriate subset of qualifying tests listed above should be applied. For instance, a newly designed wheelchair likely would need to be tested to ISO 7176 Section 8 (static strength, impact and fatigue) prior to user testing. If a new foot-support has been designed, then only the subset of testing relevant to the foot support (e.g., static strength and impact) would need to be tested.
   - **Controlled Environment User Testing:** Once the new design has passed the relevant qualifying test, a user test can be performed in a controlled environment, such as indoors in a laboratory or office space, and outdoors in a specified space. A single-user test often is performed first, and if the product is safe and reliable, multiple individuals may be invited to test the product to gather feedback from a range of potential users. These types of tests often require that a test subject perform a series of mobility tasks, while a data collector records feedback real-time while the test-subjects are performing the tasks. A discussion occurs after the testing to gather more broad feedback.
   - **Single User Community Test:** After controlled-environment testing is complete and relevant modifications have been made to the design based on the feedback, it is recommended that a single user is provided the device to perform community-based testing. Ideally a 'lead user', who will benefit from new technology and places extreme demands on the device, is the best individual to recruit for this stage of testing. This user would need to understand the risks of using a prototype product and would need to be open to providing detailed feedback on how to improve the product.
   - **Multi-User Community Test:** Once the design revisions have been made from the single-user test, a multi-user test is valuable to gather feedback from a diverse range of potential users. These tests often provide an extensive amount of sometimes conflicting feedback, some of which the design team may act on. One of the key values of this test, if performed correctly, is that it reflects the experience of the customer segment that is intended to be users.

After multi-user testing is completed and the feedback is positive about the product, it typically is ready to launch into the market. Good practice, though, is to provide a channel for continuous feedback about the product from the clinical service providers and wheelchair users, so that quality and safety issues are identified immediately and can be addressed through design revisions.

Product Procurement Recommendations

Product procurement is the process of selecting and purchasing products. This could occur at several scales. For instance, a wheelchair clinic may procure products so that they have an inventory to provide to their clients. At a larger scale, procurement can happen at a national or sub-national (e.g., provincial) level. The recommendation we provide in this section is for large-scale purchasing such as what would occur at a national or sub-national level, but the same principles would apply at a smaller scale level. A critical aspect of procurement is that the products that are purchased are appropriate for the client population in that they are low-cost, repairable locally and meet the user's needs in their environment. Assuring the products are appropriate requires expertise in contracting, clinical service provision and technical aspects of wheelchairs. Because a single person usually does not have all of these skills, purchasing committees often are established to support procurement.

We recommend the following sequential steps be taken to support procurement of appropriate products.

1. **Situational Analysis:** To ensure that the right products are being purchased, it is important to know the range of product needs by the client population, how many of what types of products (e.g., basic vs. intermediate) are needed, the environment in which they will be used, and the service capacity in the region that the products will be delivered. This is accomplished by a situational analysis. A comprehensive situational analysis can help to avoid pitfalls such as products failing in the environment, products being delivered in an inappropriate way and an incorrect range of products available for the needs. Some basic tools for performing situational analysis are available in the ISWP Policy Toolkit.
2. **Develop Solicitation:** Once the range and numbers of needed products are established through the situational analysis, a solicitation (or tender request) should be developed to outline the range and numbers of products needed. The solicitation often includes the following sections: Specifications for the different product categories; numbers of products requested in each product category; qualification testing required (e.g., ISO 7176 testing and test reports); required documentation to demonstrate that products meet the specifications, and stipulations related to warranty, delivery and spare parts.
3. **Open Solicitation:** Once the solicitation is completed, it should be opened for bid for a set period of time, such as 60 or 90 days. Solicitations that are received should undergo a cursory review by someone on the purchasing committee so that any solicitations that do not meet all of the requirements are rejected outright.
4. **Solicitation and Product Review:** Selecting a manufacturer or supplier to receive the contract to provide the wheelchairs is an important step and should be decided by the purchasing committee based on the quality of the products, the capacity of the supplier to deliver the products, past experience with the supplier and the cost. This is best done through an in-person meeting with all of the products available to review and test by the purchasing committee.

Acronyms

APC – Advancing Partners & Communities

APDK – Association for the Physically Disabled of Kenya

COG – Center of Gravity

FDA – Food and Drug Administration (U.S.)

ISO – International Organization for Standardization

ISWP – International Society of Wheelchair Professionals

LRE – Less-resourced Environment

PSD – Postural Support Device

R&D – Research and Development

TAB – Tension Adjustable Backrests

USAID – U.S. Agency for International Development

WC – Wheelchair

WHO – World Health Organization

WSTP-B – Wheelchair Service Training Package-Basic

WSTP-I – Wheelchair Service Training Package-Intermediate

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