



OPTIMIZING SELF-PROPULSION AND REDUCING RSI RISK

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From the 2010 U.S. Census, there are at least 3.6 million people who use wheelchairs in the United States (<http://www.census.gov/prod/2012pubs/p70-131.pdf>). Unfortunately, this is not broken down into type of wheelchair used, but it is clear that there are a large number of individuals who use wheelchairs in this country.

People who propel manual wheelchairs are at high risk of repetitive stress injuries in their upper extremities. Manual wheelchair users have 49 to 73 percent risk of developing carpal tunnel syndrome and 59 percent risk of developing pain in their upper extremities (Yang et al, 2009). This includes rotator cuff tears that are expensive to treat and can cause a manual wheelchair user to become a power wheelchair user, which adds additional costs and lifestyle changes, such as van purchases, and can result in a decreased quality of life (Alm et al, 2008; Boninger et al, 2004). The pain affects all aspects of the individual's life and can result in lost days at work or increased need for assistance with personal care.

When providing manual wheelchairs, therapists and suppliers strive to improve their client's function and independence. This can be achieved through a combination of choosing the correct equipment, configuring the equipment properly and teaching the client the best propulsion methods.

STARTING OFF

When doing an evaluation for any type of client, there are some basic things that should be assessed. As with any therapy evaluation, a proper mat evaluation is necessary. For wheelchair users, strength, passive motion, sitting balance, spasticity, pain and skin condition are especially important areas for evaluation. These should be assessed on a mat table to ensure the person's baseline function outside of a wheelchair. Simply looking at a client in their current equipment can lead to problems being overlooked.

If pain is present during the evaluation, assessment of location, type and severity is very important, as well as what causes the pain to increase and lessen. This needs to be evaluated before determining propulsion ability.

CHOOSING THE CORRECT WHEELCHAIR

There are many categories of manual wheelchairs. For the purpose of this article, we will focus on wheelchairs that are designed for individuals to propel full time.

Wheelchairs for short-term use are not well designed for efficient, independent propulsion, which can lead to injuries.

Unfortunately, wheelchair terminology is not necessarily helpful to clinicians and suppliers when trying to determine correct equipment for their clients.

Lightweight wheelchairs refer to chairs that generally weigh more than 30 pounds. For an active user who may need to also load their wheelchair independently into a vehicle, this is not a low-weight chair. Additionally, this type of chair has very limited ability to adjust the axle position, which can increase the difficulty of propelling and therefore decrease function and increase injury risk.

Ultralight wheelchairs tend to be the best type of wheelchair for people who self-propel. These chairs are made in a variety of materials such as aluminum, titanium and carbon fiber. The benefits of each material have been studied and are too extensive to address in this article. However, the benefits of each material should be considered so the correct frame is chosen for each client. Low weight improves the user's propulsion ability and makes the chair easier to load into a vehicle independently. Weight of chair is very important but not the only consideration for choosing an ultralight wheelchair.

Ultralight wheelchairs are the only class of wheelchairs that has the rigid frame option (Picture 1). Rigid frame wheelchairs are sturdier and allow more energy to go toward propulsion rather than movement of the frame. Folding frame wheelchairs in this category have improved their rigidity

significantly by adding a second seat rail, or a saddle, to secure the cross brace when the chair is in use, but those chairs are still slightly heavier and slightly less efficient to propel than their rigid counterparts. Ultralight wheelchairs improve push speeds, distance of propulsion and decrease energy expenditure when compared to standard wheelchairs (Beekman et al., 1999).

The ultralight class of wheelchairs has the most adjustability and ability for customization. This category of wheelchair allows for maximal adjustment of horizontal and vertical center of gravity that is not available in the other styles of frames. As will be discussed below, it is especially important to position the wheels in the correct location to allow the person to most effectively propel the wheelchair. Other styles of wheelchairs without this adjustability prevent the user from effectively accessing the wheels so that function and independence are lessened and the user will have greater difficulty completing activities of daily living.

Wheelchair choice should always involve discussion of transportation, living situation, and home and work accessibility. In some cases, decisions must be made based on these factors that supersede what might be recommended strictly based on propulsion. One example would be someone with a car-top wheelchair carrier. That style of carrier may require the use of a folding frame wheelchair, rather than a rigid frame.

For new wheelchair users, guiding them to the best style of wheelchair for their needs is preferable. However, if they desire to try different styles of wheelchair frames, effort should be made to set the chairs up identically and to have the user try them on multiple surfaces. Many times new users choose one frame over the other simply because the chair set-up is better for them. This has caused users to choose chairs they later regretted, because they were not properly counseled.

WHEELCHAIR DESIGN

After selecting the correct type of wheelchair for an individual, the appropriate design and set-up of the wheelchair is very important to maximize function and to lessen the risk of developing upper extremity injuries. The best wheelchair can be difficult to propel if the design of the wheelchair is not appropriate for the person using it.

The RESNA Position Paper on the Application of Ultralight Wheelchairs includes many more measurements than discussed here and can assist in making the best selections as this paper provides guidelines and rationale for properly setting up an ultralight wheelchair, as well as many other considerations that are important when discussing wheelchair provision (DiGiovine et al., 2012).

SEAT WIDTH

The first measurement to be determined is seat width. Many therapists and suppliers were taught that chairs should be approximately 2 inches wider than the client. In most cases, following that “rule” results in seats that are too wide and limit people’s function. Assuring the seat width is as narrow as possible without compressing the user is recommended. This is usually a seat width that is the same or even 1 inch narrower than the person’s sitting hip width (Picture 2).

A chair that is too wide causes increased shoulder abduction and wrist flexion, which can make the chair more difficult to propel and it can cause upper extremity injury. Additionally, wider chairs can decrease sitting stability, because the person slides sideways in the chair as they propel. A person should feel connected to their chair, and this only happens with tighter seat widths. Finally, when the chair is too wide, it can affect the individual’s ability to navigate through doorways, which can limit access and function.

SEAT DEPTH

Seat depth is important to ensure an upright sitting position that is best for propulsion (DiGiovine et al, 2012). A seat that is too short can increase the load on the buttocks increasing the risk of pressure injuries. A short seat depth also shortens the frame length, which increases the amount of weight on the casters, and can make the chair more difficult to propel.

A seat that is too long can put pressure behind the knees and causes people to slide forward in the chair to relieve the pressure on the back of the knees. If the person slides forward, they must go into a posterior pelvic tilt, which puts an increased amount of pressure on the sacrum and can result in pressure injuries. The posterior pelvic tilt also frequently results in forward rounded shoulders, which increases risk of shoulder injuries during propulsion. Longer seat depths also limit the ability for people to reach under their legs and move them for transfers and sitting adjustments. This is especially true for paraplegics and quadriplegics who do not have active leg movement and must lift their legs with their upper extremities.

When determining the correct seat depth, the goal is to maximize the weight on the rear wheels to optimize propulsion efficiency and maneuverability. For many self-propellers, an ideal seat depth is at least 2 inches shorter than the person’s measured sitting depth. This assures proper support and allows for leg management.

FRONT FRAME BEND

Depending on the manufacturer, the front frame bend is either the angle the front frame makes relative to the floor, or the angle that the front frame makes relative to the seat (Picture 3). It is important to understand how this is measured. On chairs where the angle is relative to the seat, the angle changes if the seat slope is changed. Tighter or larger angles make the chair shorter,

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which improves maneuverability and also accommodates people with tight hamstrings. Because the hamstrings attach at the hip and past the knee, if the knee extends too much, it pulls the person into a posterior pelvic tilt, which can cause forward rounded shoulders and poor propulsion positioning. Accommodating properly for tight hamstrings allows the person to sit upright and propel. Generally, the larger a front frame angle a person can tolerate, the easier it is for them to function throughout the day.

SEAT HEIGHT

The desired sitting height needs to be discussed when deciding the seat height of the wheelchair. Front seat height is determined to some extent by the length of the lower legs. The footplates need to be positioned at a length to support the feet while ensuring that the thighs and buttocks are properly supported and the footplate is high enough to prevent contact with the ground, ideally at least 2 inches. The seat height of the wheelchair also affects access to tables and other work surfaces. When a person has a longer lower leg length, the front seat height restricts clearance under standard tables and desks. Shorter stature people can have the opposite problem. If the chair is simply designed around their height and lower leg length, then the chair may be too short and user may feel that they are always a kid at the adult table. This should be thoroughly discussed with the individual so proper seat height, as well as proper environmental modifications, can be made as needed.

The rear sitting height is also affected by the vertical position of the rear wheel. If the person sits too low in the wheelchair, they will have to flex their elbows and abduct their shoulders to access the wheel, which increases the risk of shoulder impingement. If the person sits too high in the chair, they will have to fully extend their elbows to reach

the wheel, limiting the arc of hand contact on the rim, decreasing push length, and resulting in ineffective propulsion. The ideal rear seat height, relative to the handrim, is when the user's elbow is in a position between 100 and 120 degrees of elbow flexion when the hand is on top of the handrim (Picture 4) (Boninger et al., 2000; van der Woude et al., 2009). This has been shown to cause the least pressure in the shoulders, elbows and wrists, and decrease the risk of injury from propulsion.

SEAT SLOPE

Seat slope is the difference between the front seat height and the rear seat height. When the seat is sloped, the rear of the seat is lower than the front. Finding the perfect amount of seat slope for each person is important, as it affects sitting balance, transfers and wheel access. People with less trunk control may need larger seat slopes to maintain their balance. However, if the slope is too large and the upper extremities are weak, the person may not be able to transfer out of the chair because they have to slide uphill. Additionally, if the slope is large, the person may sit too low, relative to their wheels, so propulsion is more difficult. In most cases, a minimum of 2 inches of seat slope is used.

CENTER OF GRAVITY

Moving the rear wheel forward or backward relative to the person impacts the center of gravity of the chair. By moving the rear wheel forward, the center of gravity is moved forward, which puts more weight on the rear wheels as compared to a more stable, rearward position with the weight more balanced between the rear wheels and the casters.

The most efficient center of gravity is one that is set as far forward as possible without compromising the person's stability (Medicine C&SC, 2005). For most people, optimal placement is when the axle of the rear wheel is under their middle finger when their hand hangs straight down to their side. This is frequently 2-3 inches in front of the backrest depending on the type of backrest used. To find the best balance for a person, have them push from a stand-still position. If the chair is too tippy when the rider initiates a push, the front casters will come off the ground. This could result in the wheelchair tipping over backward. The desired forward position of the rear wheel is when the person can easily propel, but also easily pop the chair into a wheelie, when desired.

A more forward center of gravity can reduce rolling resistance, which improves propulsion and minimizes the risks of developing repetitive stress injuries. Each person's needs are different. More active wheelchair users frequently will want a more responsive chair, while someone new to self-propelling will need to learn wheelchair mobility skills prior to feeling comfortable with a very forward rear wheel position. For new users, assessing them a month or two following initial delivery usually allows the center of gravity to be better adjusted for them and their lifestyle.

BACKREST HEIGHT

Selecting the correct backrest height can significantly affect propulsion. A taller backrest can provide more trunk stability, but can interfere with propulsion. Lower backrest heights allow the scapulae to move during propulsion, which allows for greater shoulder motion (Yang et al, 2012). This improved motion of the shoulder and scapulae helps to decrease push frequency.

When selecting the back height and whether the user requires other lateral or anterior trunk support, the individual's trunk control must be considered (Cherubini and

PICTURE 1



PICTURE 1B



Picture 1: Folding vs Rigid Frame Wheelchair (Courtesy of Sunrise Medical and TiLite)

Melchiorri, 2012). For individuals with limited trunk control who require deep backs or lateral supports, keeping the back as low as possible while supporting the user properly is recommended. For individuals with slightly decreased trunk control, placing the back 20mm below the scapulae is recommended. When an individual has normal trunk control, placing the back in the lumbar region prevents interference with propulsion.

REAR WHEEL CAMBER

Increased camber places the top of the wheel closer to the individual, which improves propulsion, as the handrims are easier to reach. Increased camber also increases the lateral stability of the chair (Perdios et al, 2007). However, increased camber also increases the width of the chair, affecting access through doors. For most individuals, 2-5 degrees of camber works well, as long as the user can navigate through doorways.

TIRES

Pneumatic tires have a more comfortable ride than solid tires. However, solid tires are used frequently due to ease of care and no risk of punctures. Research has shown that air tires have less rolling resistance as compared to solid tires, which means these are easier to propel (Sawatzky & Denison, 2006). This remains true even when the air tires are poorly inflated. Many air tires are manufactured that have better protection from punctures than standard air tires. Consideration of air tire use is recommended to lessen the forces required for propulsion, which will improve function and lessen injury risk.

HANDRIMS

The size and design of the handrims affect propulsion. Standard handrims can be slippery and hard to hold, which can reduce push efficiency. Plastic coated handrims can improve propulsion in individuals with limited hand function. Because these handrims create friction to improve control, this resistance can result in abrasions to the hands when going down ramps or uneven surfaces. Some of the newer coated handrims have decreased this friction, but wheelchair users can also use gloves to lessen the risk of injury.

The use of ergonomic handrims has been shown to decrease pain in wrists and hands during propulsion (Koontz et al, 2006). These handrims use specially designed rims and provide a contoured surface for the individual's thumb and hand during propulsion which positions the hand more naturally and results in less extreme positions of the wrist and hand.

Picture 2:

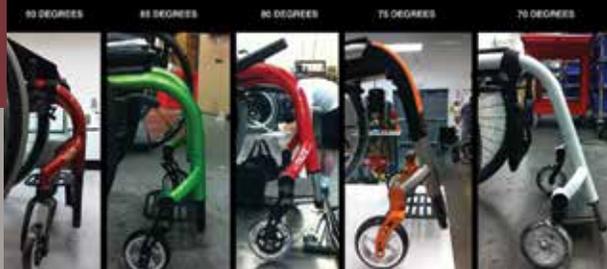
Properly selected hip width versus a chair that is too wide



PICTURE 2

PICTURE 2B

PICTURE 3



Picture 3: Front Frame Bend (Courtesy of TiLite)

PICTURE 4



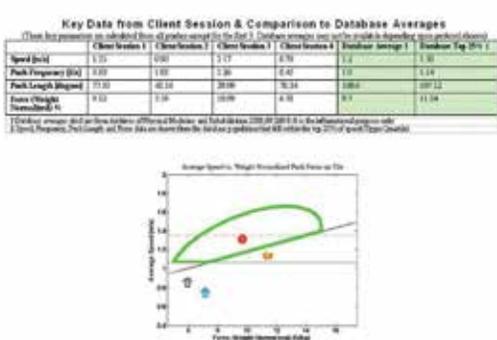
Picture 4: "B" is recommended. (Illustration from Medicine CfSC., 2005)

PICTURE 5



Picture 5: Two styles of power assist systems

PICTURE 6



Picture 6: Comparison of an individual's propulsion to the SmartWheel Database (Courtesy of Out-Front)

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Evaluating propulsion with different styles of handrims is an important part of the process to determine the best equipment for an individual, especially for users who are reporting upper extremity pain at either the shoulder or wrist, after years of self-propulsion.

POWER ASSIST SYSTEMS

For users who can propel a manual wheelchair, but may need assistance in some circumstances, power assist systems can be very helpful. If the person is unable to self-propel at least at walking speed due to decreased upper extremity strength, coordination, pain or causing shortness of breath, then power assist can be considered, especially for community mobility needs. Power assist can help to decrease pain from propulsion, especially when going long distances or over uneven terrain and ramps. These systems attach to the wheelchair and either augment the person's push or function like a power wheelchair. Some systems attach directly to the wheel through the hub while others attach to the back of the chair or the rear axle (Picture 5).

There are benefits and drawbacks to each type of power assist system. For users who will be loading the wheelchair into and out of a vehicle, the weight of each system needs to be discussed. Some systems are larger and bulkier than others, which could affect a person's ability to independently load the system into a vehicle. Additionally, some systems require more hand control to stop and start the motors. Individuals with quadriplegia may not be able to safely use some of the systems. A trial with the recommended system is a must to assure that it meets the needs of the person and that they can operate it safely.

PROPULSION ASSESSMENT

As discussed above, many of the adjustments and designs of wheelchairs affect propulsion. As there are no "must" settings, it is important that a wheelchair is properly adjusted for each person. The best way to do this is to perform a propulsion assessment and propulsion training, if needed. Propulsion can be assessed using high- and low-tech methods. Both are designed to be done in clinical settings and should be completed during evaluation, delivery and training. This assessment will ensure proper wheelchair set-up and design so the user has the least risk of developing upper extremity injuries from propulsion. Repetitive motion injuries can occur due to the high frequency of push strokes, combined with the increased force needed to propel a chair that has not been optimally configured.

Instrumented handrims (Smart Wheels) provide objective data about propulsion, including kinetic and temporal spatial data. The information is displayed in a graph (Picture 6). A database of wheelchair users' propulsion can be compared to an individual's propulsion.

The data shows a user their efficiency of propulsion and can help to teach more efficient push mechanics such as using long, smooth strokes, which uses less force to maintain an effective propulsion speed. The data, including the graphical display, can also be sent to payer sources to justify why a certain wheelchair set-up or style is necessary for an individual.

For clinics that do not have access to instrumented handrims, information can be obtained with the use of items that most clinics do possess. A stopwatch can be used to assess how long it takes an individual to propel a fixed distance. A video camera can record push frequency and push style. This data can also be used to document an individual's propulsion ability and help to improve it or justify necessary equipment.

PROPULSION TRAINING

Time should be spent at delivery and during follow-up appointments to teach the individual the best, most efficient propulsion technique for them. Video and kinetic data can help to provide feedback to the user to teach the best propulsion pattern.

The most common technique selected by wheelchair users is a single-looping method in which the hand is above the handrim during the recovery phase of propulsion (Boninger et al., 2002). However, the best technique for injury prevention is the semi-circular pattern where the hand remains below the handrim during the recovery phase of propulsion. This method results in a lower push frequency and decreased forces generated for propulsion for most individuals.

PEDIATRICS

Therapists and suppliers frequently design wheelchairs for children very differently than they do for adults. Many children who are wheelchair users will use them throughout their lifetime, so their risk of developing upper extremity injuries from chair propulsion may be greater. Despite this risk, chairs designed for children are frequently not as lightweight, are significantly wider than the child, and frequently have swing-away leg rests with decreased leg rest angles. This leaves children with chairs that are too large, may weigh more than the child, and have leg rest angles that cause them to sit with a posterior pelvic tilt and forward rounded shoulders in their wheelchairs. This lessens the child's ability to be functionally mobile and can increase their risk of developing repetitive stress injuries. With the invention of true pediatric frames designed more for function, but that incorporate growth, wheelchairs for children should follow the same considerations as those for adults to maximize function and decrease injury risk.

TAKE HOME

Many strategies can help to prevent the development of repetitive stress injuries in individuals who propel manual wheelchairs. By carefully evaluating and treating each client as an individual when selecting and designing their wheelchair, the user can reach their highest level of function.

CONTACT THE AUTHOR

Lauren may be reached at
ptlauren@aol.com.

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