RESNA Position on the Application of Ultralight Manual Wheelchairs

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A. About This Paper

This is an official Position Paper on Professional Practice from the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA). As such, it has been prepared in accordance with the specific guidelines and approval process defined by the RESNA Board of Directors for Position Papers.

See https://www.resna.org/Portals/0/Documents/Position%20Papers/RESNA-Position-Paper-Procedures-approved-7-12-2018.pdf for a complete description of this procedure.

Key aspects of this procedure include:

1) Establishment of a Working Group of three or more experts to author the paper, using evidence from the published literature, documented best practices, and other input from experts in the field as the basis for the content.
2) Review of the draft by at least two subject matter experts from the relevant RESNA SIG or PSG, as well as all interested SIG or PSG members, and subsequent revisions.
3) Circulation of the revised draft to RESNA members and others for a 60-day public comment period, and subsequent revisions.
4) Review of the revised draft by the RESNA Board of Directors, and subsequent revisions.
5) Final approval of the paper by the RESNA Board of Directors.

Final Approval date: October 2022

B. Purpose

The purpose of this document is to share typical clinical applications and provide evidence from the literature supporting the application of ultralight manual wheelchairs (ULWCs) to assist practitioners in decision-making and justification of wheelchair recommendations. It is not intended to replace clinical judgment related to specific client needs. A RESNA Position Paper is an official statement by RESNA. Position Papers are not intended to be formal, scientific meta-analyses. Rather, they use evidence and expert opinion to summarize best practices for assistive technology (AT) devices, evaluation, and service delivery. Position papers provide a rationale for decision-making for practitioners; and explain the medical or functional necessity of AT devices and services for policymakers and funding sources.

C. Abbreviations and Definitions

The following is a list of abbreviations of keywords and definitions that will be utilized throughout the Position Paper. In addition, ultralight manual wheelchair and ultralight weight manual wheelchair will be used interchangeably to reflect both a common clinical practice and Medicare terminology (US only), respectively.

Abbreviations:

- Assistive technology (AT)
- Center of gravity (COG)
- Healthcare Common Procedure Coding System (HCPCS)
- International Classification of Functioning, Disability, and Health (ICF)
- Manual wheelchair (MWC)
- Mobility related activity of daily living (MRADL)
- Repetitive strain injury (RSI)
- Rolling resistance (RR)
- Spinal cord injury (SCI)
- Ultralight or ultralight weight manual wheelchair (ULWC)

Definitions:

- **Center of Gravity (COG) adjustment**: The vertical and horizontal position of the rear wheel in relation to the mass of the wheelchair user and their device. When a MWC has a COG that can be adjusted to meet the needs of a user, the chair can then provide an improved position of a user's center of mass over the rear wheels. This is one of the defining characteristics of an ULWC.

- **Lightweight wheelchair (K0003):** As defined by Medicare, a lightweight wheelchair (K0003) weighs between 34-36 pounds (15.42-16.33 kg) and has a weight capacity under 250 pounds (113.40 kg) (Medicare Coverage Database, 2020)

- **High-strength, lightweight wheelchair (K0004):** As defined by Medicare, a high-strength, lightweight MWC weighs less than 34 pounds (15.42 kg) and has a lifetime warranty on the side frames and cross braces. K0004 is the Healthcare Common Procedure Coding System (HCPCS) code for high-strength lightweight wheelchairs. The high-strength lightweight wheelchair does not have rear wheel adjustability. (Medicare Coverage Database, 2020).

- **Ultra lightweight manual wheelchair (K0005):** As defined by Medicare, an ultra lightweight manual wheelchair (ULWC) weighs less than 30 pounds. (13.61 kg) without the front riggings, has a lifetime warranty on the frame and cross brace, and has an adjustable rear axle wheel position. K0005 is the HCPCS code for ULWCs (Medicare Coverage Database, 2020). It should be noted that this definition of an ULWC was adopted in 1993 and does not take into consideration the significant technological, design, and material advances as they relate to manual wheelchairs. The ULWC is configurable and customizable to the unique needs of the client and requires specialized evaluation, fitting, training, and follow-up.

- **International Classification of Functioning, Disability, and Health (ICF):** A holistic framework for describing and organizing information on functioning and disability. It provides a standard language and a conceptual basis for the definition and measurement of health and disability. The ICF was approved for use by the World Health Assembly in 2001 (WHO, 2002).

- **Repetitive Strain Injury (RSI)**: RSI is often used interchangeably with an overuse injury. In this document, the authors have chosen to use RSI to represent an injury or dysfunction that arises when repeated activity at high forces over a prolonged period resulting in pain, decreased function, and loss of participation.

D. Introduction

SCOPE

This paper is intended as an update to the previous position paper published by RESNA in 2012 and to focus on literature that has been published since that time. Therefore, it was pragmatic to summarize previous sections of the paper published in 2012 for which the information is still relevant and current. This paper highlights additional patient populations, includes new clinical applications of the information, expands on how wheelchair configuration influences wheelchair skills, and aligns with the recommended procedures for the development of RESNA position papers which was created after the first position paper on ULWCs.

This document is intended to compliment the principles of the International Classification of Functioning, Disability, and Health (ICF) which recognizes the role of extrinsic factors and their impact on disability as well as the relevance of associated health conditions and their effects on quality of life (WHO, 2002).

For the purposes of this document, an ULWC is defined as a fully customizable (adjustable and/or configurable) wheelchair that minimizes overall weight, is designed as an individual’s primary mobility device, and does not include features such as tilt or recline. The total weight of an ULWC depends on numerous components incorporated into the overall design of the wheelchair and includes the seating system (seat cushion and back support) as well as any other accessories. These additions are necessary to meet the unique postural support requirements of the user. Consequently, the final overall weight of the system (wheelchair, seat cushion, back support, postural supports, and additional accessories) may vary. Prior work has defined an ULWC as less than 30 pounds (13.61 kg), (Hastings, 2000; Medicare Coverage Database, 2020) or less than 25 pounds (11.34 kg) (Cooper, 1996). Currently, numerous wheelchairs weigh less than 20 pounds (9.07 kg) depending on added components. Given the intent of this document as a guide for application as opposed to design, a specific product weight cut-off will not be utilized to define the recommendations made in this position paper.

This document is supported by a scoping literature review, textbooks, clinical experience, and clinical applications to support the importance of ULWC provision (See Appendix A for scoping review process).

Statement of the Problem:

For individuals who use manual wheelchairs (MWCs) as a primary means of mobility, there is an abundance of research that demonstrates risks for repetitive strain injury (RSI) to the extremities, postural support challenges, and decreased community involvement. Further, MWCs that are inadequate in meeting a user's needs can lead to decreased participation and quality of life. These issues are often related to insufficient prescription and customization, including both configuration and adjustments of the MWC and seating components, which can result in pain, discomfort, limited functional ability, and long-term secondary complications.

In general, there is a lack of knowledge regarding the best clinical practices related to assessment and service delivery, combined with limited formal education for healthcare providers regarding best practices. This can result in inadequate equipment provision and associated training with subsequent poor outcomes and limited functional potential for the wheelchair user. It is imperative that clinicians and equipment service providers understand the importance of matching the equipment to the user and invite active participation from the user to identify specific needs. Evaluating and recommending MWCs should focus on the functional potential of the user and their long-term goals, rather than reimbursement circumstances alone.

RESNA's Position

It is the position of RESNA that ULWCs, which are customizable, including configuration and adjustability while minimizing overall weight, are the only acceptable choice for individuals who rely on MWCs for independent manual mobility, regardless of propulsion method and across multiple care settings and diagnoses.

The design and construction of ULWCs should use the most current technology to provide fully customizable wheelchairs made of materials that minimize weight, including but not limited to aluminum, titanium, magnesium, and carbon fiber. Various seat configurations are available with ULWCs, and they can accept external positioning devices such as cushions, back supports, and postural support accessories.

The Supporting Evidence

Participation

Within the ICF, there is a clear understanding that participation is influenced by health conditions, activity, body functions & structures, environmental factors, and personal factors. Participation is defined by the World Health Organization as "involvement in a life situation" (WHO, 2002). This may include mobility in a variety of settings, self-care, home life, work and education, community involvement, and interpersonal relationships. The ULWC offers a unique opportunity to enhance participation and quality of life outcomes. Currently, there is limited published research specific to the relationship between ULWC and participation. Clinical experience and expertise may contribute to a greater understanding of this relationship. When a mobility device is matched to the individual, it can facilitate more active engagement, meaningful interactions, and opportunities, as well as a person's satisfaction with how they are able to participate. It is important to note that this opportunity is only realized if the ULWC is properly and individually configured and if user training (e.g., wheelchair skills, maintenance) is integrated into the service provision process (Arledge et al., 2011).

Mobility device quality has been tied to participation outcomes among wheelchair users. Specifically, one should consider repairability, ease of maintenance, and device reliability (Magasi et al., 2018). Users with higher wheelchair skills and wheelchair maintenance skills have demonstrated greater levels of participation (Sakakibara et al., 2014). Community accessibility is also tied to participation (Smith et al., 2016) and care should be taken to integrate environmental considerations into ULWC provision for all environments the user will encounter both inside and outside the home.

Personal factors that can limit participation among people using MWCs may include pain, fatigue, impaired cognition, psychological comorbidities, and decreased level of function (Smith et al., 2016; Moon et al., 2013; Mashola et al., 2021). For example, MWC users with rotator cuff pathology report higher levels of pain during activities of daily living (Fornier-Belley et al., 2017). Pain and upper extremity dysfunction can also increase the need for personal care with resultant limitations of independent functional mobility (DiGiovine et al., 2012). Post-surgical recovery secondary to repetitive strain injuries associated with MWC use can be extremely challenging for a person that lives independently as it can take up to 4 months after shoulder repair to return to pre-operative levels of strength and function (Patel et al., 2018). A decrease in function may also cause limitations in self-care, the ability to complete a full workday, transfer, drive a vehicle, engage in meaningful social activities, and fulfill family roles. Direct healthcare costs as well as indirect secondary costs related to the need for more equipment, caregiver support, and supplemental income, can be increased when upper limb function is compromised in a person who self-propels a MWC (Moon et al., 2013).

Repetitive Strain Injury (RSI)

Preserving upper limb function in people who self-propel a MWC is a consistent focus of clinical research, position papers, practice guidelines, and evaluation considerations for wheelchair prescription. While some guidelines are limited to upper extremity dysfunction in persons with spinal cord injury (SCI) (Sawatzky et al., 2015), it is important to understand that RSI impacts many populations, with a significant impact on function and quality of life. When a limb, joint, ligament, or muscle group is exposed to higher demands occurring over a prolonged period, injuries related to overuse often occur (Patel et al., 2018). This dysfunction is often defined as an overuse injury or an RSI.

RSIs of the upper extremity can be present in the shoulder, elbow, and wrist. This dysfunction can include numbness, tingling, orthopedic pain, referred pain, muscle atrophy, and decreased functional range of motion (Sawatzky et al., 2015). Across a variety of different cohorts of MWC users, the incidence of shoulder pain reached as high as 78% of MWC users (Mashola et al., 2021). The shoulder is not specialized or designed for the repetitive activities required when a person propels a MWC (Moon, 2014). With a variety of upper extermity activities, the shoulder is required to both mobilize and stabilize at the same time, which can result in fatigue, muscular imbalance, impingement, pain, degeneration, and chronic conditions (Requejo et al., 2015). Repetitive actions of scaption (scapular elevation occurring as the arm is flexed and abducted) contribute to RSI at the shoulder (Patel et al., 2018). Clinical symptoms of carpal tunnel syndrome are reported in up to 65% of MWC users with an even greater number (75%) demonstrating diagnostic evidence of the syndrome (Asheghan et al., 2016). RSI is not limited to the upper extremity, the lower extremities are also under excessive strain during unilateral (hemi) propulsion or bilateral lower extremity propulsion (Charbonneau et al., 2013). Specifically, calf and hamstring cramping was reported during single-foot propulsion by able-bodied participants (Heinrichs et al., 2020a). RSI can also develop secondary to activities that do not occur in the wheelchair, such as during transfers or loading the MWC into/out of a vehicle. Addressing RSI requires a comprehensive approach that includes wheelchair selection and configuration, client education, and possible functional retraining.

There are two types of risk factors to assess for RSI: intrinsic and extrinsic factors. Intrinsic risk factors are specific to the person such as the age when a person first starts propelling a MWC, current chronological age, total duration of time that a person is propelling (Finley & Ebaugh, 2017), nature and duration of illness or injury, extent of muscular imbalance, amount of narrowing of the acromiohumeral space, and body weight (Ferrero et al., 2015; Fornier-Belley et al., 2017; Mozingo et al., 2020; Patel et al., 2018; Sawatzky et al., 2015). As an example of body weight as an intrinsic factor for RSI, increased peak force applied to the handrim to propel a MWC is anticipated for an individual who is overweight or obese. Extrinsic risk factors include the biomechanics of overhead reaching, type and number of daily tasks, number and technique of transfers, pressure management, propulsion force and frequency, MWC chair configuration including postural supports, and rolling resistance (Mozingo et al., 2020; Patel et al., 2018; Walford et al., 2019; Sawatzky et al., 2015; Lin et al., 2014; Ott & Pearlman, 2021). Increased propulsive cycles increase the risk of impingement and the likelihood of developing chronic RSI over a lifetime of propulsion (Requejo, Furumasu et al., 2015). Transfers can be required up to 20 times per day. Greater than 12 transfers a day is related to an increased risk of pain among individuals with SCI (Ferrero et al., 2015). Consideration should be given to chair configuration and adjustments, as well as the intrinsic and extrinsic factors that can increase the risk of RSI.

The selection of an ULWC allows for optimal fit and performance that cannot be obtained when using a standard or lightweight wheelchair. It is imperative for clinicians to consider that to optimize propulsion conditions and limit RSI, proper wheelchair configuration must exist alongside training in exercise, strength, propulsion, and wheelchair skills (Sawatzky et al., 2015). There is an opportunity to think proactively during equipment selection and configuration to decrease the negative secondary complications from RSIs and pain through the selection and configuration of a MWC. Specific components of selection and configuration will be discussed in the following sections.

Rolling Resistance

Rolling resistance is a frictional force that results from the rear wheels and casters traversing the ground and is a base principle that relates to numerous other topics covered throughout this document. It can have a significant impact on the user's propulsion efficiency and should be carefully considered when selecting and configuring an ULWC.

As a MWC user propels forward, they impart a force on the handrim that rotates the rear wheels, and the material of the tires and casters deform and rebound. As a result, energy is lost during deformation and rebounding in the form of rolling resistance. For this paper, mainly straight trajectories with forward propulsion are discussed in relation to rolling resistance since it is the most researched scenario and turning forces tend to be higher and not fully documented. It is also important to understand that resistance during startup propulsion is higher than during steady-state active propulsion (Sprigle & Huang, 2015).

For efficient propulsion, rolling resistance should be minimized so that each propulsion stroke traverses the user as far as possible, thus reducing the risk of upper extremity RSI (Brubaker, 1986; Ott et al., 2020). Rolling resistance is impacted by various influencers including tire type, and composition, caster size and composition, horizontal axle position, camber, toe angle, load, load distribution, speed, tire pressure, and various environmental surfaces which are discussed below. Therefore, if more than one influencer is present, rolling resistance is the sum of all the influencers' respective parts. One comprehensive study was able to evaluate these factors at a component level to understand the relative influence and this can be used as prioritization for clinical decision-making. The factors that can have the most influence on rear wheels should be prioritized in clinical recommendations to mitigate rolling resistance as seen in Table 1 below (Ott et al., 2020).

Table 1 - Ranked Level of Importance for Rolling Resistance Mitigation*
1. Tire Type – pneumatic over solid over airless inserts 2. Toe – less than 1 degree [in or out] 3. Tire pressure – 80% or more of max inflation pressure 4. Load – distribution of weight is more significant than small weight changes 5. Camber – up to 5 degrees 6. Speed - normal propulsion speeds around 1 m/s [2.24 mph]

*Information from (Ott, 2020).

Overall, it is important to understand the impact of equipment selection and configuration on rolling resistance and use the evidence to guide best practices. Each MWC user should be assessed individually, and attention given to functional potential, personal goals, wheelchair skill level, and environment of use.

Equipment Selection and Configuration

The ULWC is more customizable than other categories of MWCs. Customization provides for individualized configuration and adjustability. Both characteristics are essential for people who are first beginning to propel a MWC, those who have a lifetime of experience to know exactly what works for them, and those who have a condition that changes over time. While studies suggest that durability is comparable across models, client feedback and opinions are important factors in determining overall functional outcomes and client satisfaction. The ULWC provides the best options for maximizing functional potential, preventing secondary complications related to MWC use, and maintaining function over time. The most frequent considerations are overall weight, configurability, and compatibility with seating and postural supports.

Weight: Minimizing the overall weight is a key characteristic of an ULWC as compared to other MWC configurations. Increased weight increases rolling resistance. Tire and caster performance are directly proportional to the load on them and rolling resistance increases as the load increases (Ott et al., 2020). The load is comprised of the user, device, and accessories and should be minimized if possible. As compared to standard lightweight wheelchairs, when propelling an ULWC the handrim forces are lower, work per distance traveled is lower, self-selected speed is higher, and shoulder and elbow flexion are higher (Oliveira et al., 2019). Secondary to their lower weight and increased configuration options, ULWCs may be more efficient and may lower the risk of injury (Oliveira et al., 2019).

However, without proper ULWC configuration relative differences in weight may not be appreciated. If a heavier MWC is properly configured, it may feel subjectively lighter than a lighter poorly configured wheelchair. Some studies show that there is no perceived difference in propulsion effort or energy expenditure with weight differences as high as 5 kg [11.02 pounds]) when properly configured (Sagawa et al., 2010; Lin et al., 2015.

Therefore, when comparing ULWCs, it is important to consider the configurability and client preference over the published wheelchair weight, which does not usually vary greatly among ULWCs (Cowan et al., 2009; Sagawa et al., 2010). However, if the user is routinely lifting their wheelchair in and out of a vehicle, smaller increments of weight may have more impact since the user will have to lift the chair into and out of the car from less-than-optimal ergonomic positions.

Configuration: Wheelchair configuration, when adjusted and fit to each individual, will have the greatest impact on the maneuverability, propulsion efficiency, and function of ULWCs. In a review of studies related to configuration, it was found that every component, in relation to each other, has a significant impact on the user (Medola et al., 2014). Therefore, while we discuss each aspect of configuration independently, it is important to identify and recognize the impact that each choice has on the next. Wheelchair mechanics, stability, and biomechanics of propulsion are determined both by the position of each component relative to the other as well as to the user (Medola et al., 2014). It is the combination of configuration options that will create an overall positive or negative impact.

Important components to consider related to configuration include backrest height and angle, seat angle, vertical and horizontal rear wheel position, rear wheel camber, the position of lower extremity supports (height and angle), frame design, and rear wheel and front caster type and size. While not inclusive of every possible component selection, each of these components considered individually will change the user's interaction with his or her environment and affect outcomes and user satisfaction. It is also advised to consider the geometry of the frame, folding or rigid, or a specific style of rigid frame when determining the ideal configuration of components, seating, and postural supports.

Critical measurements applicable to ULWCs:

Seat width – Seat width, or rear seat width, is measured at the back of the frame near the back canes. Accurate measurement of the wheelchair seat width is critical to create pelvic stability, provide access to the rear wheels for propulsion, and optimize upper extremity alignment during propulsion. If the seat width is too narrow or too wide, postural asymmetries and pressure injuries may develop. As an additional consideration, in the pediatric population it is recommended that a chair is selected so that it can grow with the child instead of expecting the child to grow into the width of a chair.

Seat depth – Seat depth is determined by the length of the surface supporting the pelvis and the lower extremities. Seat depth, when correctly determined, will provide pressure distribution along the sitting surface as well as postural stability, while allowing for clearance of the posterior aspect of the knee. On ULWCs, seat depth and frame depth may have the ability to be individually selected to optimize the user's weight distribution. When the seat depth is too long, increased pressure at the popliteal fossa can result in pressure injury, and edema, and can also cause the user to slide into a posterior pelvic tilt. If the seat depth is too short, the lower extremities will not be supported, and pressure may be increased over the bony areas of the pelvis. Seat depth may also be influenced by leg length discrepancies, spasticity, and propulsion style.

Seat-to-floor height – Seat-to-floor height is the seat surface height at both the front and the rear frame of the wheelchair relative to the ground. The front seat-to-floor height is determined by lower leg length, ground clearance, propulsion style, and postural support required. When individually configured, the front seat-to-floor height provides stability, accommodates cushion height, and maximizes environmental accessibility. The rear seat-to-floor height is selected to create passive pelvic stability and to increase access to the rear wheels and handrims to optimize propulsion effort.

Seat slope – As defined by Lange & Minkel, seat slope represents the measured difference between the front and rear seat-to-floor height (2018). There is no optimal seat angle for everyone, it is determined by an individualized assessment. An increased seat slope can increase stability and the perception of stability by the user, particularly among those with decreased trunk control (Cloud et al., 2017). When selecting a seat angle, user stability should be considered as well as pressure distribution on the seated surface. Additionally, the ability to transfer in and out of the wheelchair and foot propulsion may also be affected and should also be considered, since a more significant seat slope may make these activities more challenging (Regier et al., 2014).

Leg rest and footplate support position – Positioning of the lower legs and feet impacts pressure distribution, seated stability, and weight distribution. This is influenced by the location of the footplate and the angle of the leg rest relative to both the seat slope and the ground. While the front frame angle does not equate to the knee flexion angle, it is important to understand that a larger frame angle may be associated with increased knee flexion. For positioning fore and aft, an increased knee angle is shown to decrease rolling resistance (Medola et al., 2014), hence improving propulsion efficiency. For optimal pressure distribution and seated postural stability, leg rest configuration must be consistent with lower leg length and available hip and knee range of motion. Based on the leg rest position, the foot support(s) location is determined with consideration of the available ankle range of motion.

Back support height – Backrests positioned below the scapula provide increased upper extremity range of motion, better handrim contact, and improved push angle. The desired result is decreased push frequency, which can lessen the impact and probability of RSIs to the upper extremity (Medola et al., 2014). Backrest height may also affect available trunk mobility and overall functional reach. In combination, a lower backrest height and increased seat angle can optimize function and positioning, even for MWC users with compromised trunk control.

Back support angle – The back support angle is the angle created by the back posts or back support in relation to the ground. When the back canes and/or back support are perpendicular to the ground, that is considered a 90-degree back support angle. When “closing” the back, this creates an angle that is less than 90 degrees. By doing this, the pelvis may gain stability, but this may limit the range of motion and may also compress soft tissue. When a backrest is “open” or set beyond the 90-degree angle, this may improve static sitting balance when combined with the correct height and material of the back support. The back support angle may also be set to accommodate non-reducible postural asymmetries. Even though the angle is in relation to the ground, the evaluation will allow the comparison of the back angle to the seat plane angle for individualized configuration.

Horizontal position of the rear wheel axle – As stated in the 2005 Clinical Practice Guideline: Preservation of Upper Limb Function, numerous studies support the recommendation that ". . . the rear wheel should be placed as far forward as possible without compromising the stability of the user." A more forward rear wheel position decreases push frequency and handrim forces and improves maneuverability. A forward axle position is the most efficient for rolling resistance. A higher portion of the total weight, including the user, device, and accessories, should be distributed to the rear-wheels which have a lower rolling resistance than the front casters (Caspall et al., 2013; Sauret et al., 2013). Rolling resistance during turning is also reduced with greater body weight over the rear wheels except for fixed wheel turns (Misch et al., 2020; Sprigle & Huang, 2020). Propulsion efforts, as measured by oxygen consumption, are reduced with a more forward axle position (Lin et al., 2015). Horizontal axle position has been shown to influence propulsion effort more than physical fitness, body mass, or posture (Lin & Sprigle, 2020).

Vertical position of the rear wheel axle - An optimal vertical position is considered the height where the user has an angle between the upper arm and forearm that is between 100-120 degrees, with the hand at the top of the handrim (Van der Woude et al., 2009; Slowik & Neptune, 2013). This position also usually correlates with the pad of the second finger being near the center of the rear axle when the user is seated in the MWC with the arm hanging vertically downward and the elbow fully extended. Vertical rear wheel axle position that is too high or too low creates challenges for the user in accessing the handrim for efficient propulsion and can contribute to RSI if increased upper extremity forces and/or repetitions are required.

Camber – Camber of the rear wheels brings the top of the wheels closer to the individual and can be used to improve lateral stability and maneuverability for turning. However, one must consider the impact on the overall width of the chair and accessibility (e.g., door widths). Common camber angles (up to 5 degrees) can slightly increase rolling resistance, but it is not significant enough in everyday wheelchairs to outweigh user preference for increased access to the push rims (Ott et al., 2020).

Rear wheel alignment: Toe angle, or rear wheel alignment, can influence propulsion. Misalignment of the rear wheels occurs when the wheels are not parallel to each other and therefore, experiencing toe in or toe out. Toe angle occurs when the front edges of the wheels are closer together or farther apart than the rear edges. In this configuration, the wheels combat each other to propel in a straight line, causing forces in an outward direction that do not contribute to forward momentum and are considered an energy loss in rolling resistance and scrub torque. Therefore, higher amounts of toe cause higher amounts of rolling resistance. As a contributor of rolling resistance, it was found that the alignment should be kept within ±1 degree of equal alignment to reduce its influence. When changes are made to the axle tube, camber, seat-to-floor height, or caster height, the result can unintendingly induce toe into the rear wheels (Ott et al., 2020). A community-based study revealed that toe is present in everyday wheelchairs, including ULWCs, causing increased propulsion forces (Ott & Pearlman, 2021).

Component selection for ULWCs

Rear wheels and tires– Since rear wheels and tires make direct contact with the ground, they have an influence on ride characteristics, comfort, and rolling resistance. Rear wheels can be impacted by physical characteristics, style, and material properties. While the diameter is typically selected based on the requirements for push-rim access, a larger diameter tire will have a lower rolling resistance. Furthermore, smaller tire widths tend to have a lower rolling resistance, but the material compound that composes the tire is also a factor (Kauzlarich & Thacker, 1985). Tire pressure is inversely related to rolling resistance. High-pressure pneumatic tires (over 100 max psi) have been proven to have a lower rolling resistance than lower-pressure pneumatic tires (under 100 max psi), solid tires, or airless inserts (Ott et al., 2020).

Overall, a high-pressure pneumatic tire is the most efficient tire for most scenarios followed by low-pressure pneumatic tires, which are subsequently followed by solid tires (Ott et al., 2020). Underinflated tires increase the workload of the MWC user, regardless of the surface (Booka et al., 2015). Tire pressure should be maintained such that the tire always has 80% or more of the maximum inflation pressure. However, it is important to understand that an under-inflated tire may have a lower rolling resistance than an airless insert (Ott et al., 2020). One study found underinflation to be a common occurrence in the community (Ott & Pearlman, 2021).

Airless inserts, or solid tires, are overall the least efficient tires because they have the highest rolling resistance with straight trajectories, though resistance is reduced with turning (Fallot et al., 2019; Ott et al. 2020; Sprigle et al., 2019; Sprigle & Huang, 2020). A benefit of solid tires can be reduced maintenance – the user will never have to change a flat tire; however, wear can develop which changes their efficiency.

Casters – Similar to rear wheels, caster size and diameter are inversely related to rolling resistance (Zepeda et al., 2016; Chan et al., 2018). However, casters have numerous factors such as the material composition or outside profile, that may have a significant impact on caster rolling resistance rather than strictly the caster diameter itself (Ott et al., 2020), indicating that all caster features must be considered when configuring an ULWC. It is important to note that the caster diameter can change the maneuverability of the wheelchair. Of note, load distribution has demonstrated a more significant impact on rolling resistance than on caster size. Specifically, when 30% or less of the load distribution is on the casters, the diameter does not influence rolling resistance (Zepeda et al., 2016). While it is known that casters have an overall greater rolling resistance, the best practice is to position the rear axle as forward as possible with the consideration of the user's wheelchair skills and balance point to reduce the load on the casters (Ott et al., 2020).

Frame design and material – Attention should be given to the design of the frame (folding vs rigid) in relation to the user's environment, physical requirements, and functional activities. For example, transportation of the wheelchair may be a factor in frame design selection depending on the type of vehicle and if the user loads the chair independently or requires assistance. In terms of materials, it is understood that ULWCs are made of a variety of high-strength, lightweight materials including, but not limited to, aluminum, titanium, and carbon fiber. These materials can provide specific ride characteristics and relative advantages and disadvantages. In combination with the frame design and ULWC components, the frame material may potentially impact propulsion efficiency and vibration experienced by the user. The clinician and wheelchair provider should understand the benefits and drawbacks of frame design and material.

Selection of seating and postural supports – While one study suggests that seating should be considered before the wheelchair configuration (Taylor et al., 2015), the order of selection has not been adequately studied. However, the evidence indicates that they must not be considered separately. The height of a wheelchair seat cushion, for example, will have an impact on the position of the user relative to the rear wheels.

It is also shown that the application of postural supports can enhance the impact of optimal wheelchair configuration and function. In a study of MWC users with SCI, solid back supports were compared to traditional sling-style back supports. The solid back supports were shown to affect the position of the pelvis and spine, resulting in better posture, range of motion, push angle, push time, and decreased push frequency, all of which contribute to minimizing the potential of RSI. Though not statistically significant, the study also showed improvement in functional tasks such as forward reaching, timed forward wheeling, ramp ascent, and descent (Presperin Pederson et al., 2020).

Power assist and power add-on devices: Additional solutions are available to reduce the force required to propel a manual wheelchair and number of pushes required to travel a set distance. These are often known as power assist solutions, which can be used in combination with ULWCs. This paper does not attempt to address all considerations of power assist, except to say that adding this technology to a MWC has been shown to increase propulsion efficiency, increase the distance a person is able to travel during the day, lower the perceived exertion of propulsion and decrease amount of shoulder range of motion required to propel (de Klerk et al., 2018). It has been reported that the perception of power assist devices for people who use MWCs is that there is potential to increase mobility, participation, and well-being; however, great care should be taken to assess the style and type of power assist solution that is selected for each individual (Khalili et al., 2021). The addition of power assist to an individually configured ULWC could provide the best possible functional outcome compared to manual wheelchair propulsion. An additional review of the evidence is needed on the use of power assist technology and its complementary nature when used with ULWCs, which is outside the scope of this paper.

Wheelchair Skills

Wheelchair skills are an important key to optimizing the potential impact and opportunities for independence that an ULWC affords. Wheelchair mobility skills training to optimize function and safety is highlighted in the RESNA Wheelchair Service Provision Guide (Arledge et al., 2011). Greater wheelchair skills, in combination with higher self-efficacy, are associated with improved life-space mobility (Sakakibara et al., 2014). Wheelchair skills training should be part of the wheelchair service provision process and should be considered in conjunction with wheelchair setup and environmental factors (Smith et al., 2016). Training should include skills that may be needed to navigate indoor environments (such as propulsion, turns, opening and closing doors), as well as skills needed to traverse community environments (such as inclines, curbs, and wheelies). Adaptive equipment may be needed to enhance wheelchair skills performance and could include gloves or tubing wraps on the handrims (Taylor et al., 2015). Alternative or customized handrims can also be useful for wheelchair skills acquisition.

Propulsion biomechanics may not come naturally to a person using a MWC, therefore training and education must be included in the wheelchair provision process. The four primary patterns of wheelchair propulsion include: arc, semi-circular, single loop over, and double loop over (Boninger et al., 2002). Single loop over is defined by hands going above the rim during recovery while the double loop over repeats this looping pattern again. The arc pattern is often defined as having a very short or sharp path of movement with a limited recovery phase (Boninger et al., 2002). The semi-circular pattern, where hands fall below the handrim in a recovery cycle of the push phase, has been shown to improve propulsion efficiency, decreased joint loading, and force generation (Sawatzky et al., 2015). There are applications for other patterns in high resistance environments, at start-up, or for short bouts of mobility (e.g., arc pattern for ramp ascent).

Weight shifts are critical for managing and redistributing pressures on seating surfaces, which is critical for reducing the risk of pressure injuries and should be included in skills training. In studies of sitting behavior, more than 50% of days measured included 2 hours without a weight shift which far falls short of the recommended frequency (Sonenblum & Sprigle, 2017).

More than half of MWC users with SCI report being unable to negotiate high curbs, hold a wheelie for 30 seconds, complete a floor-to-chair transfer, or descend stairs (Hosseini et al., 2012; Kirby et al., 2016). For many of these skills, a more forward axle position is important and can be achieved with an ULWC. While these skills may be critical to participation, it is not surprising that proficiency is low as the incidence of training in advanced wheelchair skills is reduced as compared to wheelchair propulsion (Taylor et al., 2015). A systematic review and meta-analysis demonstrate the Wheelchair Skills Training Program has a clinically meaningful effect on the capacity to complete wheelchair skills (Keeler et al., 2019). This program can be considered a resource for clinicians in providing wheelchair skills training.

Barriers to increased independence using an ULWC may include external bracing, orthopedic restrictions, and pain (Taylor et al., 2015). These factors should be considered and accommodated as best as possible with the wheelchair configuration. Common impediments to wheelchair skills training related to wheelchair setup can include rearward axles and axles that are not adjustable, anti-tippers located close to the ground, backrest height that interferes with scapular movement, footplates that interfere with foot propulsion, seat-to-floor height that is too large (cannot foot propel), seat width that is too large (cannot reach wheels), and user dependence for removing footrests or wheel locks (Smith & Kirby, 2015). As such, skill performance can be enhanced with adjustable rearward axle position, anti-tip devices with 3-5 cm (1-1/4 to 2 inches) clearance, and teaching users how to remove footrests and disengage wheel locks.

Among novice wheelchair users a learning process is demonstrated during which there are changes in wheelchair speed, handrim forces, motor force, rolling resistance, and stability (Eydieux et al., 2020). Further, compared to expert users, novice MWC users required a greater number of pushes, with shorter pushrim contact and higher muscle activity (Symonds et al., 2016). Clinicians should be mindful of these changes when providing training interventions. Diversity of training approaches could be considered including 1:1 training or group training (Keeler et al., 2019; Worobey et al., 2016). Attention should be paid to the dosage of training. A pilot study of a shorter duration training intervention (2 hours) showed improvements in self-efficacy but not wheelchair skills, suggesting that training may enhance efficacy before improving ability (Sakakibara et al., 2014).

Durability

While the consensus is that ULWCs are made of better components and materials, as compared to other MWCs types, it is still important to consider durability and the cost of repairs over time. Overall, the durability of ULWCs has remained constant over time. In a sequence of studies (Gebrosky et al., 2013, 2018, 2020), investigators evaluated various ULWCs using = ANSI/RESNA testing. When testing a variety of models of various configurations and materials, some failures are found in every category, but ULWCs continue to perform better, and longer on these standardized tests than lightweight MWCs. For more details on these testing parameters, you can visit the ANSI/RESNA website or refer to WC-1 standard on the RESNA website.

When differentiating between ULWCs that appear to have many similarities, clinicians and equipment providers should ask about the standards the chair has been tested to and identify if the chair has been tested by an independent organization. For example, while the European Union (EU) and Australia/New Zealand require testing by an independent certified testing lab, this is not required by the FDA in the United States or ADP, the main funding body in Ontario, Canada; in the latter settings the manufacturer usually conducts their testing at their own facilities. Testing performed by independent labs is viewed as more objective and less biased than testing performed “in-house” by the manufacturer of the MWC.

Conclusively, ULWCs remain the most durable MWCs. While their cost may be higher than lightweight MWCs, they are less prone to breakdowns that could leave the user without their primary means of mobility, or worse, cause injury to the user. The selection of an ULWC should not be completed solely based on testing results, but it should be considered in conjunction with all the parameters discussed and based on the functional goals and input of the user.

Alternative Propulsion

Most of the reviewed literature focuses on individuals with SCI who propel a MWC using bilateral upper extremities. The needs of MWC users who utilize alternative propulsion methods should also be considered because an ULWC can be configured to fit and accommodate the unique needs of these individuals. Individualized chair recommendations should apply to people who propel their chair with one side of their body, both lower extremities, or one extremity. Although not diagnosis dependent, some presentations may include acquired brain injury, multiple sclerosis, cerebral palsy, cerebrovascular accident (also referred to as a stroke), amputation, poliomyelitis, and incomplete spinal cord injury including but not limited to central cord syndrome, just to name a few. People who use alternative propulsion methods are often not evaluated for complex rehabilitation technology. In addition, they are also at risk of postural impairments, limitations in their activities of daily living, discomfort, lack of confidence, decreased activity tolerance, feelings of isolation and loss of social engagement, lack of training of wheelchair skills and overuse injuries due to poor equipment selection and provision. (Charbonneau et al., 2013; Heinrichs et al., 2020a; Heinrichs et al., 2020b; Mandy et al., 2019; Murata et al., 2014; Requejo, Furumasu et al., 2015). While many of the principles of chair configuration previously discussed also apply to alternative population styles, additional considerations are described below:

High resistance environments - The selection of components such as front casters, rear wheels and tires, and the position of the rear wheel are critical to ensure reduced rolling resistance and support more independent and efficient propulsion. People who use one lower and one upper extremity to propel will have increased difficulty as rolling resistance on certain surfaces increases, especially with a standard wheelchair configuration. Backward propulsion may decrease the effort and load required because of the use of the quadricep musculature as opposed to pulling with hamstrings, as well as the fact that when propelling backward, the shifting of the trunk into extension will take more weight off of caster wheels (Charbonneau et al., 2013). However, backward propulsion is often not a functional solution as it requires a significant cervical range of motion, trunk stability, visual tracking, coordination, and perception which may be limited in persons with acquired brain injuries, multiple sclerosis, cerebral palsy, amputation or cerebrovascular accident.

Postural support - When working with people who will use one limb or one side of their body to propel, the need for postural support evaluation and intervention is critical due to the expected presence of muscle imbalance, inconsistent patterns of spasticity, visual deficits leading to postural changes, and the need for support of the hemiparetic side of the body while allowing movement of the intact side of the body. Research in this patient population is provided through a pilot study and those with able-bodied participants, which do not allow generalization of the findings to users with mobility impairments, but may create the foundation for future larger-scale studies. One pilot study determined that providing a more upright trunk angle with a solid back support and decreasing the amount of seat slope and seat cushion contour to allow more movement of the propelling lower extremity may increase propulsion efficiency in people with hemiplegia (Regier et al., 2014). Evaluation of postural support needs during static and dynamic activities is required as an increased loss of positioning can be observed when using a lower extremity for propulsion. It is possible to also consider a solid seat pan for increased postural stability when lower extremity propulsion is used (Heinrichs et al., 2020a; Heinrichs et al., 2020b; Regier et al., 2014).

Configuration – Often the seat-to-floor height for a person using one or both lower extremities to propel is different from a typical upper extremity propulsion set-up. The front seat-to-floor height must be appropriate (often lower) to accommodate heel strike and optimize muscle activation for knee flexions and extension without exceeding the available range of motion. The typical set-up of the front seat-to-floor height facilitates a 90-degree angle at the hip and knee while in a static position with the entire foot contacting the ground (Regier et al., 2014). A slightly less significant seat slope may be indicated when using the lower extremities compared to using the upper extremities, so evaluating this within small ranges of adjustability could be critical to functional outcomes (Regier et al., 2014). In healthy individuals, biomechanical evidence indicates that speed of propulsion and force reactions were higher as the seat-to-floor height was lowered when propelling with both legs; however, there is a threshold when a chair is too low to the ground and the hip range of motion demands make it more difficult to propel (Murata et al., 2014). Seat-to-floor height may also pose an added challenge of needing to support each lower extremity differently through the cushion or footrest height by adding height to the impaired lower extremity for positioning and pressure redistribution (Heinrichs et al., 2020a). Seat depth must also be considered to decrease any potential interference with knee flexion during the propulsion phase (Heinrichs et al., 2020a).

Propulsion patterns - When evaluating propulsion effectiveness, recommendations for contact angle and patterns of movement have yet to be standardized when using the lower extremities as they have with the upper extremities. Evaluating changes in propulsion characteristics such as stride length (the distance traveled between initial contact of the foot on the ground between two propulsive cycles), speed, cadence, amount of active hip range of motion required, the position of the heel or foot initial contact, heel whip, coasting between cycles, upper body or trunk rocking, and duration of time the foot remains in contact with the ground may be useful when determining appropriate chair configuration (Heinrichs et al., 2020a; Murata et al., 2014). When using only one lower extremity to propel on smooth surfaces, able-bodied participants experienced changes in propulsion as the front seat-to-floor height was lowered. Subjectively, it was reported that propelling at a lower front seat-to-floor height was not as difficult compared to a higher front seat-to-floor height. Objective testing revealed increased speed and effectiveness of push-based upon completion of a 10-meter push distance (Heinrichs et al., 2020a).

Considerations for training - Individuals propelling with one or both lower extremities or using a unilateral (hemi) propulsion technique may experience challenges when acquiring wheelchair skills. Consideration should be given to coordination, motor planning, vision, cognition, activity tolerance and pain. When utilizing alternative propulsion methods, specifically in the older adult population, skill development is often overlooked which leads to dissatisfaction with equipment and loss of independence with mobility. When older adults are provided with more customized and appropriate MWCs designed for independent mobility, their wheelchair skills, and satisfaction rating increase. Wheelchair skills training sessions should be implemented in the plan of care as part of ULWC provision for all propulsion styles. Additional sessions may be required, altering patterns based on specific activities, as well as shorter bouts of activity (Charbonneu et al., 2013; Mandy et al., 2019; Requejo, Furumasu et al., 2015).

The application of an ULWC can apply to a variety of propulsion styles and should be evaluated based on the functional need for a customized MWC that can only be obtained with the measurements, accessories, and configurations available on an ULWC. Additional research is needed on alternative propulsion methods utilized by diverse groups of people who use MWCs.

Environment of Use:

ULWC configuration should consider the environments a user may encounter. Focus should be given to the environments where the user spends most of their time or has identified difficulties with functional propulsion.

The types of surfaces in a MWC user’s home and community will have a large impact on rolling resistance and should impact clinical choices. When compared to hard surfaces, carpeted surfaces increase rolling resistance (Lin & Sprigle, 2020; Sprigle & Huang, 2020). When specifically compared to tile, carpeted surfaces increased rolling resistance by 82% on casters and 121% on drive wheels (Sprigle et al., 2019). Propulsion costs can increase on carpet by 48% for straight propulsion and 63% for turns (Sprigle & Huang, 2020). Furthermore, if the MWC user propels over carpet with low tire pressure, they are approximately doubling the resistance felt during propulsion as compared to propulsion on a hard surface, such as smooth concrete, with a fully inflated tire. When comparing rolling resistance across carpet and tiled surfaces, larger diameter casters have less rolling resistance across carpet (Ott et al., 2020). In conjunction with caster size selection, distributing the weight into the rear wheels may minimize the probability of the front casters dropping into softer surfaces which increases rolling resistance (Ott et al., 2020). Ultimately, the time traversing these soft surfaces should be minimized to limit rolling resistance and protect the upper extremities from RSI.

Maintenance

Maintenance and repairs are a diverse subject that covers a large range of issues for wheelchair users. The prevalence of wheelchair breakdown is related to wheelchair features as well as user characteristics, such as funding source and race (Henderson, G. et al., 2020; Toro et al., 2016; Worobey et al., 2021; Worobey et al., 2012). It has been shown that repair times, costs, and other demographic information drastically change the access to and ability of repairs to be completed. The need for wheelchair repairs carries secondary adverse consequences which include being stranded inside and outside of the home, missing work and school, injuries, being forced to use a backup chair, increased risk of pressure injuries, and increased risk of rehospitalization. (Henderson, G. et al., 2020; Toro et al., 2016; Worobey et al., 2021; Worobey et al., 2012; Hogaboom et al., 2018). These consequences are likely even higher for those who do not have access to a backup wheelchair or the financial means to accommodate a breakdown. Despite this awareness, knowledge of wheelchair maintenance among both clinicians and MWC users remains limited.

Wheelchair maintenance training should be an integral part of the service delivery process and is recommended as a core step in wheelchair provision by the World Health Organization. A comprehensive wheelchair maintenance training program and questionnaire were developed for wheelchair maintenance (Toro et al., 2016) and have demonstrated effectiveness among MWC users (Worobey et al., 2021). Available resources that have been developed from this work include clinician reference manuals on how to teach wheelchair maintenance, a maintenance checklist, and direct-to-user web-based training programs (Appendix B). Additionally, every ULWC includes a User Manual that includes a maintenance schedule and often details most adjustments of the wheelchair. It should be provided at delivery to each user. Routine maintenance can prevent a catastrophic device failure and prevent injuries to the user. Further, checking items like tire pressure regularly reduces rolling resistance and makes the device easier to propel. Just as routine maintenance to a car is essential, such as checking the oil and changing the brakes, so too is wheelchair maintenance to optimize the performance of an ULWC.

Populations Served

As previously stated, much of the original research on ULWCs has focused on individuals with SCI. However, there is an expanding body of evidence that includes wheelchair users across a spectrum of diagnoses, ages, and care settings. Based on the literature and clinical experience there are populations that are often overlooked or treated differently when considering MWC selection. The difference is sometimes based on age or the user's entry into the rehabilitation network. For example, older adults with multiple and varied comorbidities, are often not given the same consideration for ULWCs as a person with a SCI. Additionally, a client with a progressive disease such as Multiple Sclerosis or Parkinson's may not be provided the most appropriate MWC because they often do not access the typical rehabilitation resources. Differences across populations must be considered with the selection and configuration of an ULWC customized to the user's unique needs.

Pediatrics:

Similar to adults, the pediatric population has also been identified as requiring individualized wheelchair configuration (Ezik et al., 2017). Individualized configuration of MWCs is achievable for all ages. Children may require multiple assistive devices which are often combined based on activity demands. For children with cerebral palsy, wheelchair propulsion can be a more, or equally efficient means of mobility compared to ambulation based on energy efficiency (Abe et al., 2019). These findings indicate the need for increased experience and understanding of the application of an ULWC in this population. It is integral to consider the unique developmental considerations of pediatric users, to follow them through their lifespan, and to accommodate necessary adjustments as their mobility needs evolve.

For pediatric users, mobility needs should be addressed through a MWC configuration that optimizes a variety of propulsion patterns, decreases the potential future risk for RSI, and supports wheelchair skills training. Additional research is needed on the long-term impact of the variation of propulsion styles as well as the development of pain and RSI in children less than 8 years. Findings specific to pediatric MWC users include:

- For propulsion patterns, children are exposed to the same amount of force with upper extremity propulsion as adults. Adult and pediatric populations differ in that children often fluctuate between propulsion styles and have demonstrated the use of a fifth propulsion pattern that has been described as a combination of arc and semicircular (Slavens et al., 2015; Schorenberg & Slavens, 2016). The selection patterns vary by the environment being navigated, the child's diagnosis, and chronological age.
- Evidence indicates that children are at a similar risk of impingement, although there is less pain reported with childhood-onset propulsion compared to adult-

onset propulsion (Schorenberg et al., 2014). The Wheelchair Users Pain Index has been utilized in children as young as 8 years old and would be a recommended outcome measure for a child who will be self-propelling for their mobility (Dysterheft et al., 2015).

- Wheelchair skill training has been shown to reduce fatigue and pain in children ages 8-18 using a modified Wheelchair Skills Test (Rammer, 2019). For children ages 7-19, training and objective assessments have been shown to be effective (Schotter et al., 2019).

While the causes of the variance between adult wheelchair users and pediatric wheelchair users have not been thoroughly researched, there are known differences in development and behavior that may drive discrepancies. For example, a pediatric wheelchair user is more likely to ask for assistance traversing high-resistance terrain than an adult wheelchair user and more likely to take rest periods when fatigued.

While the concept that pediatric wheelchair users are "not just little adults" is acknowledged and understood, following basic guidelines for wheelchair configuration, and adapting to the individual's needs, will likely result in positive outcomes.

<u>Older Adults:</u>
The older adult client may be overlooked for the customized mobility solutions ULWCs provide due to their complex care needs related to co-morbidities, decreased access to these solutions based on their discharge disposition such as to a skilled nursing facility, or the expectation that their functional outcomes are impacted negatively by their chronological age. In long-term care facilities specifically, there is a history of poor wheelchair prescription and set-up as well as decreased access to appropriate technology and limited wheelchair skill training (Giesbrecht & Miller, 2019; Smith & Kirby, 2015). It is imperative to include this population in the provision of ULWCs as the number of older adults continues to rise. (Giesbrecht et al., 2015).

It has been shown that mobility limitations create participation limitations in older adults. Life-space mobility has been defined as the variety of "different areas in which people conduct their lives". As such, access to an appropriate mobility solution can increase the life-space mobility of older adults, which can improve their independence in activities of daily living, self-reported health and depressive symptoms, and quality of life-related to health outcomes (Sakakibara et al., 2017). When someone has limited life-space mobility, their travel distance has a much smaller radius, such as within a bedroom of a home or living facility. As life-space mobility increases, this extends to the rest of the home, their community, or even the person's city, state, or country. Like ambulation, wheeled mobility can have a positive impact on life-space mobility when a person can travel farther with decreased strain, complete more frequent bouts of activity, and remain in their mobility device for longer periods of time (Sakakibara et al., 2014). ULWCs provide the potential for older adults to increase their distance traveled, bouts of activity, and occupancy time.

A wheelchair that can be customized with an adjustable rear axle position should be recommended due to the benefits of reducing rolling resistance, improving push kinematics, and reducing repetitive strain injury while also providing individualized seat to floor height measurements regardless of age. Care should be taken to assess propulsion methods, configuration measurements, propulsion efficiency, and wheelchair skill acquisition. The potential for increased time for wheelchair skill testing and training may exist specifically in long-term care facilities where previous experience of the skills is extremely limited (Smith & Kirby, 2015).

Clinical Applications

Clinical Application 1:
Lower extremity propulsion, an adult with polyneuropathy

MK is a 54-year-old female with a medical history significant for chronic inflammatory demyelinating polyneuropathy (CIDP) for 12 months with associated bilateral upper and lower limb weakness, balance impairment with associated falls (5 within the past 12 months), fatigue, neuropathic pain (distal upper and lower limbs), chronic low back pain due to spondylosis and spinal stenosis, vestibular schwannoma following right-sided craniectomy with resection and residual balance deficits and right-sided hearing loss.

MK is unable to effectively self-propel her current lightweight MWC. This is due in part to poor fitting and limited adjustment. The wheel axle cannot be adjusted, which places the axle plate in a fixed position that does not allow for efficient propulsion. In addition, MK has poor coordination and dexterity due to her CIDP and she needs to use her lower extremities for assistance in propelling. Since she is 5’3 she requires a reduced seat-to-floor height that her current K0004 chair does not achieve. Due to a lack of adjustments, she was having difficulty accessing her environment and experiencing decreased independence with mobility-related activities of daily living.

MK is not able to functionally propel her current K0004 MWC. To propel 10 meters (32.81 ft) in the K0004 chair on level ground takes her 17.47 sec (0.57 m/s), which is not functional for her required MRADLs. Further, she requires 20 pushes to traverse this distance (1.1 pushes/sec), indicating an inefficient push frequency.

When placed in an ULWC that was adjusted with the horizontal axle position and the seat-to-floor height adjusted for her small frame, she was able to propel at a speed of 10.17 sec (1.00 m/s), which almost doubled her speed of functional mobility. Her push efficiency also improved to 15 pushes, which is a push frequency of 1.4 pushes/sec. Additionally, these adjustments reduced the weight on the front casters from 30% to 25%, reducing her rolling resistance and improving her efficiency and maneuverability for self-propelling.

An ULWC chair allows fully configurable solutions and adjustability for MK and allowed her to the ability to achieve full maneuverability as well as decreased risk of secondary complications.

Clinical Application 2:
Bilateral UE propulsion, an adult with incomplete spinal cord injury

NF is a 31-year-old male who sustained an L1-level injury while performing a ski jump and subsequently falling. At the time of injury, he was initially diagnosed as a complete injury however, a recent workup revealed incomplete injury due to L5 sensation.

NF is now seven years post-injury, and he has grown very competent with his wheelchair skills and functional mobility. His need for adjustability has lessened and he is pursuing the lightest ULWC configuration possible. NF is a very active young man who is a Paralympic athlete and participates in adaptive sports in his free time; he also built his own accessible home from the ground up and is an avid traveler.

NF initially was positioned in an adjustable ULWC upon injury; the adjustability of the frame enabled flexibility within frame modifications for a new user. With NF and his roles in mind, the decision as a team was to prescribe his replacement chair as an ULWC that has more customized measurements and is configured without adjustable seat-to-floor height and without an adjustable back angle. These modifications were recommended to minimize the overall weight of the wheelchair frame as well as reduce hardware that could loosen over time. For example, a carbon fiber back support and carbon fiber accessories (i.e., camber tube) as well as the removal of the anti-tippers and armrests.

NF has been functioning with a center of gravity set at 3” (7.62 cm) and has great safety awareness and independence with advanced wheelchair skills. The team anticipates reducing the overall weight of the wheelchair by 2 pounds (0.91 kg) which will be particularly relevant for increased ease of loading his wheelchair in and out of his car. In addition, his advanced wheelchair skills of climbing stairs and curbs may be improved by reducing the overall lifting weight.

Clinical Application 3:
Bilateral UE propulsion, a young adult with cerebral palsy

AA is a 15-year-old active teenager who presents with severe dystonia and spastic diplegia cerebral palsy. Her clinical presentation includes severe spasticity in both lower extremities and dystonia throughout all extremities and trunk, with extreme extensor spasms mostly in the lower extremities. She presents with partially reducible scoliosis and kyphosis and a non-reducible pelvic obliquity. Based on her age and diagnoses, it has been determined that AA has completed regular growth cycles and should not experience any large fluctuations in size.

AA is a very active teenager who participates in school activities and plays wheelchair tennis. While she has used a power wheelchair for long-distance and outside activities, she wants to use her MWC more often so she can go out with friends and travel. She wants to improve her propulsion and have a wheelchair that is light and easy to load into a vehicle.

She has been prescribed an ULWC in the past, but her primary complaint has been: “They are always too heavy for me to push myself, why can’t it be more like my tennis chair?” On evaluation, it was determined that AA’s current ULWC was not appropriately fit for her. It measured 16 in (40.64 cm) wide, had a planar, “growable” seating system that restricted upper extremity motion, and had a COG in the most rearward position on the frame. After trial and evaluation with a demo rigid ULWC, a prescription was made that varied dramatically from her original prescription.

The new chair recommendations included changing the seat width to 13 in (33.02 cm), using an off-the-shelf seat cushion, and a back support that was low enough to allow upper extremity mobility. In addition, the rear wheel position was moved forward compared to her previous chair, allowing the COG to be below the shoulder joint. The final configuration weighed 14.5 pounds (6.58 kg) lighter than the original configuration. The appropriate fit of the chair, new seating, and position of the rear wheels helped to improve her postural stability and provided better access to the rear wheels for propulsion and reduced rolling resistance. These changes have allowed AA to be more independent when utilizing her MWC and self-propel in multiple environments, including outdoors, and perform advanced MWC skills such as wheelies.

While she had been provided an ULWC in the past, the prescriber did not consider the impact of fit and configuration on her long-term function and her personal goals. Mimicking the fit and function of her tennis chair and paying close attention to the configuration of the new rigid ULWC has made a huge difference for AA. AA and her family are much happier with her new chair, and she will be using it more frequently. She has even started a new dance class with her newfound wheelchair skills and improved mobility.

Clinical Application 4:
Bilateral UE propulsion, a young child with transverse myelitis

WB is currently a 7-year-old boy who was diagnosed with transverse myelitis at 7 months of age. He spent several months in a pediatric rehabilitation center and was eventually diagnosed with T2-T4 level of paralysis. Due to his chronological age at the onset of his diagnosis the therapy team identified he needed an external orthosis as well as dynamic positioning components to protect his posture during growth but also provide external passive support to allow for independent MWC propulsion.

From the early days of MWC propulsion, WB was provided with an ULWC with an adjustable rear axle. Although accessing the rear wheels was difficult due to his physical size, the therapy team optimized his independence as much as possible. Throughout the last 7 years, the family has continued to seek out MWC solutions that would make it easier for him to propel. They have been able to closely monitor his growth and adjust his equipment accordingly, so he is always in an optimal position.

He demonstrated early proficiency with wheelchair skill development, performing wheelies by 2 years of age. He continues to wear his thoracic lumbar sacral orthosis (TLSO) in his manual chair with a lap belt, positioning cushion, and solid back support; however, he no longer uses his ankle-foot orthoses (AFOs) or his dynamic chest strap. Between family support, wheelchair configuration, and skill development, WB has no reported upper extremity issues and will be monitored for any changes in propulsion patterns or adjustments need to his equipment. The benefits of implementing an ULWC immediately after WB's diagnosis has demonstrated there is no need to wait for a child to grow to provide them with configurable and lightweight equipment.

Clinical Application 5:
Single limb propulsion, an older adult with LE amputation

PA is a 92-year-old male veteran who presents with a recent right-side above-knee amputation, thoracic kyphosis, peripheral vascular disease, and new onset of bilateral shoulder pain during the use of a walker. PA was provided with a lightweight MWC upon discharge from the hospital. Although he was not a candidate for a prosthetic, he was provided a walker for assisted ambulation and transfers. However, within the first six months post-amputation, PA became frustrated using the walker because it was hard for him to maneuver on all surfaces and he was unable to ambulate without a caregiver or therapist present.

It was identified that Mr. A would benefit from wheeled mobility. Due to PA's advanced age and limited mobility, he may not have been considered for an ULWC, and a power wheelchair may have been recommended. A power wheelchair was not an option for PA because of challenges with in-home access, portability, and transportation. His therapy team compared his propulsion efficiency of a lightweight, high-strength wheelchair to an ULWC with a specific front and rear seat-to-floor height measurements and an adjustable vertical and horizontal center of gravity. PA attempted to use his upper extremities to propel but secondary to bilateral shoulder pain, he self-selected to use his left lower extremity to propel. Based on a wheelchair propulsion test on indoor flat terrain, PA was able to propel the 10 m (32.81 ft) in 26.7 seconds with 14 propulsion cycles with his current lightweight chair. This improved to completing the 10 m in 14.8 seconds with 8 push propulsion cycles with an ULWC.

PA's therapy team is now evaluating him for a power assist add-on for his ULWC because he has difficulty negotiating thick carpet and uneven surfaces such as ramps with his single-leg propulsion style. He has also started to show a desire to increase his independence and community access. A power assist device in combination with the ULWC will decrease the amount of caregiver assistance he needs throughout his day from his 70-year-old son and prolong his active years.

Limitations

This paper is limited by its database searches from PubMed, CINAHL, and Medline; however, a follow-up search was conducted after the initial search to confirm a comprehensive review. Furthermore, the review team ensured the appropriate papers were used by having multiple reviewers at each stage. While the search is considered a scoping review, a PRISMA-SCR guideline was followed to apply academic integrity. In addition, this is considered an update on the previous position paper and therefore, one may want to consult the original paper from 2012. One limitation is that only peer-reviewed articles were included in this update to adhere to a high quality of research required for publication. Additionally, this paper covers literature that was published until June 2021 database searches and new information may have been produced since that time. Overall, the review was comprehensive and a team approach to preserve quality and provide valid results.

Relationship of this paper to other RESNA position papers:

This position paper represents the current state of the evidence pertaining to the evaluation, recommendation, and provision of ULWCs, which corresponds to RESNA's position that all people with mobility impairments should be provided equipment with full knowledge of the current state of the evidence. It is most closely related to the RESNA Wheelchair Service Provision Guide which emphasizes the steps to understand and utilize standardized methods to recommend complex rehabilitation technology. In addition, this paper serves as an update on the evidence of the previously published "The Application of Ultralight Manual Wheelchairs" in 2012 as well as highlighting additional patient populations, new clinical applications of the information, and alignment with the recommended procedure for the development of RESNA position papers that was created after the first position paper on ULWCs.

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Appendices:

Appendix A
Summary of the position paper development

Study design and research question This was a scoping review completed according to the Preferred Reporting Items for Scoping Reviews (PRISMA). The PCC question was "What is the current body of evidence for clinical application on the use of ultralight manual wheelchair configuration, materials, propulsion demands, and ergonomics?"

Eligibility criteria
Studies in this review met the following eligibility criteria: were published in or after the year 2013 and published in an established peer-reviewed journal. Exclusion criteria included articles discussing basic wheelchairs, introductory wheelchairs, in-home use, power-assist wheelchairs, power wheelchairs, and sports wheelchair. Topics of interest included: overuse injuries, kinematics, muscle recruitment, wheelchair skills, rolling resistance/friction, novel products (row wheel, lever drives, one-arm drives), transportation of equipment, pediatric, foot propulsion, and power assist.

Search strategy
Three databases were searched from July 2020 to June 2021. Databases searched included PubMed, CINHAL, and Medline. The search string utilized in all three databases was (wheelchair OR wheelchairs) AND manual AND (ergonomics OR ergonomic OR friction OR propulsion OR pediatrics OR pediatric OR configuration OR set-up OR "set up" OR materials OR material OR durability OR stroke OR environment OR function OR skills OR life-space mobility).

Selection of sources
The Covidence program was utilized as a data organizational tool. Three investigators reviewed titles and abstracts of studies resulting from database searching. These investigators removed any irrelevant articles. Three investigators then reviewed the remaining full-text articles and voted to include or exclude them from the study based on inclusion and exclusion criteria. Two of the reviewers completed the original vote and disagreements were voted upon by the third reviewer to determine the final vote.

Data charting and management
The included articles were categorized into common themes. These themes are represented in a concept map (Figure B). Themes were then utilized as the basis for the resulting position paper. The included articles were qualitatively examined by members of the research team to draw conclusions on the current state of the evidence regarding the recommendations and use of ultralight manual wheelchairs.

RESULTS

Included evidence sources

The literature search resulted in 1198 studies. After the removal of 720 duplicates, 478 studies remained. These studies' titles and abstracts were screened for relevance. 271 studies were deemed irrelevant and removed. The remaining 207 studies were assessed through full-text review. 105 studies were excluded. The remaining 102 studies were included in this scoping review. This information is summarized in the PRISMA Diagram (Figure A).

Figure A. PRISMA diagram to represent the results of the completed scoping review

The data from the included studies resulted in 13 themes. Themes included: muscle recruitment, novel devices, repetitive strain injuries, participation, pediatrics, rolling resistance, wheelchair skills, alternative propulsion styles, durability, environment, equipment selection configuration, kinematics, and maintenance and repairs. The results of this study can be seen in the concept map (Figure B).

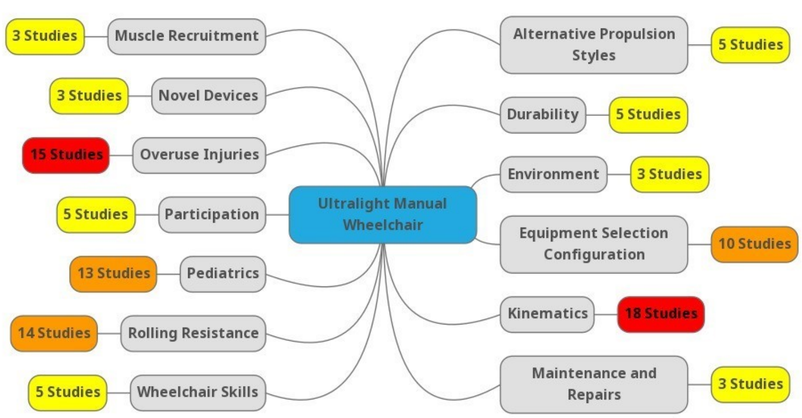

Figure B. Concept Map of the resulting themes gathered from the completed scoping review

Methodological quality and risk of bias in included studies: 102 studies were included in this scoping review. There was one qualitative study (Level of Evidence (LoE)2), one retrospective cohort study (LoE 4), six prospective cohort studies (LoE 3) three guideline development studies (LoE 5), five mixed methods studies (LoE 4), two scoping reviews (LoE 1), 52 controlled clinical trials (LoE 3), 17 cross-sectional study analyses (LoE 4), one longitudinal study (LoE 4), two randomized control studies (LoE 2), four repeated measure cross over studies (LoE 4) and one case study (LoE 5).

Appendix B:

Manual Wheelchair Maintenance Checklist

http://www.upmc-sci.pitt.edu/wmtp-materials/Manual%20wheelchair%20hands%20on%20checklist.pdf