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Evidence-Based Strategies for Preserving Mobility for Elderly and Aging Manual Wheelchair Users

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Abstract

Elderly and aging manual wheelchair (MWC) users have increased risk for accelerated loss of function and mobility that greatly limits independence and affects quality of life. This review paper addresses important issues for preserving function and mobility for elderly and aging individuals who use a MWC by presenting the current available evidence and recommendations. These include recommendations for maximizing function, by decreasing pain, improving the ability to self-propel, and prolonging mobility and endurance through ergonomics, individualized wheelchair selection and configuration, and adaptations for increasing the capacity to handle the daily mobility demands through training, strengthening, and exercise. Each recommendation is supported by current research in each relevant area.

Keywords

Elderly and Aging; Manual Wheelchair; Functional Mobility; Pain and Dysfunction; Seating and Positioning; Evidenced Based Practice; Quality of Life

Demographics of Elderly and Aging Manual Wheelchair Users

By the year 2030, the number of elderly in the U.S. will double to 71.5 million [1]. While, longer life spans are generally considered desirable, particularly when healthy years of life are increased, with an aging population and longer life expectancy come an increasing prevalence of chronic diseases and conditions associated with aging [2, 3] that can significantly reduce the quality of life. There is considerable recognition that aging and disability are two arenas that are increasingly viewed as a national and international problem requiring effective, practical, and scalable solutions [4-7]. According to data from the U.S. Census Bureau,

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approximately 18 percent of Americans have a disability involving an activity limitation, and the incidence of disability increases to 54 percent by age 65[8]. The three most compelling reasons to target the elderly and those aging with and into disability are: 1) this is the fastest growing age group in the world (Rae et al., 2010); 2) healthcare costs are highest among the older group; the elderly (age 65 and over) made up around 13 percent of the U.S. population in 2010, but they consumed 36 percent of total U.S. personal health care expenses. The average health care expense in 2010 was \$18,320 per year for a person 65 or older but only \$6,122 per year for a working-age person (ages 19-64) and 3) clinically, this group has a high rate of chronic conditions and functional limitations resulting in the high health care utilization. About 5% of all older individuals in the U.S. are currently living in institutional settings [1].

An estimated 1.5 million people in the United States use a manual wheelchair (MWC) according to the National Health Interview Survey on Disability [9]. Most use a MWC with the proportion of those using increasing sharply with age (864,000 in those 65 years and older). This population consists of many who have been using a manual wheelchair as a result of sudden onset of disability or gradual onset such as those persons with progressive diseases and elderly individuals who require a wheelchair for mobility [10]. These include those diagnosed with spinal cord injury (SCI), stroke, transverse myelitis, osteoarthritis, lower extremity amputation, poliomyelitis, myelomeningocele, GuillianBarre syndrome, multiple sclerosis, amyotrophic lateral sclerosis (ALS) and cerebral palsy, as well as older adults with neurological deficits and unable to ambulate with an aid of a cane or walker. If prescribed and configured to their individual needs, MWC use can increase independence in activities of daily living; reducing the need for caregiver assistance [11] and in turn possibly lowering the probability of placement in long term care facilities. However, a mismatch between the needs of the individual according to their functional capacities and the provided MWC may result in decreased mobility due to poorer posture, pain and fatigue, pressure ulcers; contributing to poorer quality of life and an increased need for personal assistance [12-14].

Pain and Pathology in Manual Wheelchair Users

There is a significant difference in life satisfaction between people with a disability than without. For those individuals with physical disabilities, life satisfaction increases to a maximum point at about age 45-50 and then gradually begins to decline [15]. This age closely corresponds to the age of change in physical functioning for those people who have disabilities [15-18]. As people age, there are many age related changes. Changes in skeletal muscles and joints include slower contractile speed, reduction in elasticity, impaired healing of injured muscle and increased fatigability [19]. These changes have greater impact on the individual aging with a disability. In a study of over 600 individuals with various diagnoses including Polio, SCI, Cerebral Palsy, arthritis and other impairments reported that the combination of weakness, fatigue and pain, marks the beginning of change in function in major activities [15].

Elderly and persons aging with a neurological condition experience a greater level of sensory loss, fatigue, pain, and depression [20] that further exacerbate difficulties in activities of daily living [15], maintenance of physical activities [21, 22], and increasing needs for assistance [23], and quality of life [24]. The underlying etiologies are generally impairment-specific, but

the effects are often similar across diagnosis groups [15]. For the MWC user, loss of lower extremity function often places the burden for mobility and activities of daily living on the upper extremities. People who use a MWC commonly report fatigue and musculoskeletal pain in the wrist, shoulder, neck, and back, most often due to increased demands of mobility [3, 15]. Mood and QOL is negatively impacted when individuals experience generalized bodily pain [25-27]. Further, wheelchair use and aging amplifies the health risk that further impacts functional independence including shoulder [16, 18, 21, 28, 29] and carpal tunnel injuries [29, 30], pressure ulcers [31, 32], scoliosis or postural and pelvic deformities caused by muscle weakness, paralysis or osteoporosis [32, 33], fractures [28, 34, 35], urinary tract infection [28, 33] and gastrointestinal complications [32]. These additional effects of age and duration of injury leads to significant increases in the cost associated with their healthcare [36].

Upper Limb

Structurally, the shoulder (glenohumeral joint) is poorly designed for weight bearing since the shallow socket for the humeral ball (glenoid) has only a fibrous labrum for peripheral stability and the plane of the joint is vertical. During manual wheelchair propulsion (WCP) and depression transfers, the arms are in low angles of elevation and the joint capsule is loose and its reinforcing ligaments are slack. Consequently, shoulder muscles must provide both joint stability and power for forward propulsion making them susceptible to fatigue [37, 38]. Decreased muscular force as a result of fatigue or age related weakness and neurological deficiencies can result in inadequate dynamic stability and allow the external loads of WCP to induce forces that displace the humeral head upward from the center of the socket [39, 40]. This upward humeral head migration can compress the subacromial space and the rotator cuff tendons (mainly the supraspinatus), the tendon of the long head of biceps brachii, and the subacromial bursae resulting in chronic inflammatory and impingement syndromes [30, 41] and bicipital tendinitis [29]. Prolonged impingement leads to degenerative changes in the tendons of the rotator cuff and eventually to partial or complete tears, chronic pain, and reduced function as well as decreased quality of life [42].

Postural Deformities

Spinal deformities—Elderly and aging wheelchair users are typically faced with increasing postural deformities that negatively impacts their ability to function in a wheelchair. Kyphosis and scoliosis are common spinal deformities due to a muscle imbalance, osteoporosis, weakness or paralysis [43, 44] and immobilization [45]. The most common problem associated with kyphosis and scoliosis is pain, usually more in the lumbar (lower spine) than in the thoracic (upper spine). Severe curves in the upper spine causing forward or lateral collapse of the vertebral bodies and ribs can compromise the ability for the individual to expand their lungs, swallow food or liquid, and cause aspiration. Additional pressure from the musculoskeletal ribs can affect stomach and intestinal functions. Because kyphosis and scoliosis affects the spinal alignment, wheelchair users are at an even higher risk for orthopedic injuries, and increased pain in the spine and shoulders. Asymmetry in trunk alignment causes uneven arm use. Self-propulsion becomes less efficient, asymmetrical, and they may need to use their arms to hold their trunk upright for sitting balance. Severe collapsing scoliosis or kyphosis interferes with wheelchair propulsion [43, 46] as well as breathing and eating [47].

Pelvic Deformities—In elderly and aging individuals who sit for long periods of time secondary to weakness or paralysis, pelvic obliquity and a posterior pelvic tilt are the two most common postural deformities of the pelvis. Pelvic obliquity is described when a person's pelvis sits higher on one side than the other, usually caused by asymmetry in muscle strength as in hemiplegia or hip joint contractures caused by osteoarthritis or heterotrophic ossification [45]. Pelvic obliquity exacerbates trunk imbalance and leads to an unstable base for the trunk in an upright position, necessitating the use of the hands to support the spine, compromising their ability to use their hands for activities of daily living [44, 48]. Pelvic obliquity also increases risk for pressure ulcer formation secondary to asymmetrical sitting pressures [47]. A posteriorly tilted pelvis is often seen in the elderly who have been primarily in a wheelchair or bed and have tight lumbar spines and hamstring muscles [45]. This slouched posture is associated with sacral sitting and sliding out of their wheelchair, possibly causing shearing type pressure ulcers. This slouched posture starts with the posterior pelvic tilt and ultimately limits the active mobility in the upper extremities as the upper body is slumped forward. The associated decline in range of motion of the hips from a slouched posteriorly tilted pelvis significantly limits upper extremity use and therefore activities of daily living, such as positioning and transferring and maintenance of hygiene, thereby adversely affecting quality of life [49].

Pressure ulcers

Improvement in survival rate of persons with disabilities and in the general aging population has increased the number at risk for pressure ulcers. It has been estimated that five million people in the United States have chronic pressure ulcers, there are 1.1-1.8 million people developing new ulcers each year, the financial cost and the emotional burden is heavy [50]. The two groups at highest risk are the elderly and those persons with spinal cord injury (SCI). However, advances in seating and mobility technologies have made a difference in controlling deformities, preventing pressure ulcers and improving each individual's quality of life. Aging skin loses elasticity, firmness, thickness, moisture, sensitivity and vascularity; and may reduce the tolerance to pressure and shearing forces resulting in greater risk for pressure ulcer development [51]. The incidence of pressure ulcers in persons with SCI increases with the duration of injury, 15% at one year to 30% at 20 years of follow up [35]. In a study completed in the United Kingdom, the prevalence of pressure ulcers among elderly patients in general medical practice, the probability of developing a pressure ulcer increased dramatically with increasing age. As compared to those 65 to 70 years of age, those over 80 years of age were 4 to 20 times more likely to develop a pressure ulcer [52]. Advanced age played an important role in the presence of pressure ulcers after accounting for demographic and clinical factors. An aging-related decrease in muscle mass and vascularity may reduce the tolerance of aged skin to pressure and shearing forces, leading to the development of pressure ulcers [53]. A decrease in the density of adrenergic receptors, which would have an effect on blood supply in the skin below the level of injury and collagen loss [54] may also play a role in the skin's ability to resist mechanical shear and pressure [55]. An increased risk of pressure ulcers among older adults has been shown by previous studies in the SCI population [56, 57]. Advanced age appears to be related not only to the frequency of pressure ulcers but also to their severity.

Physical Activity and Exercise

The majority of people with mobility impairments, particularly older individuals who use MWC for mobility, do not meet levels of physical activity (PA) recommended for health and disease prevention [58-60]. Inactivity in individuals with chronic disabilities, who use a MWC results in significant and costly secondary complications, such as pressure ulcers, obesity, diabetes, osteoporosis, and cardiovascular co-morbidities [61-66]. In addition to the physiological benefits, participation in exercise and sports activities by MWC users is associated with decreased depression [67] and improved community integration and quality of life [60, 68-71]. Increasing PA in this population, however, typically involves upper extremity exercise. Chronic shoulder pain and associated physical dysfunctions is a common secondary condition in MWC users that further limits mobility and participation and negatively impacts quality of life [42]. Gutierrez et al. [42] interviewed 80 SCI participants with shoulder pain and identified that higher intensities of shoulder pain (as determined by Wheelchair User's Shoulder Pain Index (WUSPI) scores [72]) were associated with lower subjective QOL scores in persons with paraplegia ($r = -0.35$, $p = 0.002$) and decreased community mobility ($r = -0.42$, $p < 0.001$). The dilemma for those who use a MWC (particularly those who are elderly) because of lower extremity paralysis and overall weakness is: how to increase PA for physiological and psychological health benefits without further increasing pain and pathology.

Consequences of Pain and Pathology

The limitations and restrictions imposed by the pain and dysfunction in elderly and aging wheelchair users can be described in the framework defined by the International Classification of Functioning, Disability and Health (ICF) [73] (Figure 1). The ICF can be an effective framework for identifying key elements that must be addressed in rehabilitation interventions [74-79] and for guiding provision and classification of assistive technology [80]. In particular, the concepts of "activity limitations" and "participation restrictions" are classified as two components of health level of the person and society. Because elderly and aging individuals who rely on MWC are dependent on their upper extremities for Activities of Daily Living and Instrumental Activities of Daily Living (ADL/IADL), pain and dysfunction (body function and structure) [81, 82] can limit ADL/IADL [53, 83-85] and negatively impact community participation and quality of life (participation restriction) [75]. Mortenson et al. used the ICF as a framework to identify and to evaluate wheelchair-specific outcome instruments that are useful for measuring activity and participation [86, 87]. They determined that wheelchair-related factors were associated with participation frequency directly and indirectly through their relationship with mobility [88]. Specifically wheelchair skills, including the ability to transfer in and out of and propel a wheelchair, were important predictors of life-space mobility and frequency of participation, and life space mobility was a significant predictor of frequency of participation. Depression was associated with poorer wheelchair skills and mobility and less-frequent participation. Similarly, better wheelchair skills predicted better self-perceived health, higher life satisfaction, and more community participation [89] and improved confidence in older adults using MWCs [90].

Strategies to Preserve Mobility for Elderly and Aging MWC Users

The elderly population, once lively, active and independent slowly or abruptly become disabled. The elderly wheelchair users are the weakest and most frail individuals often with multiple diagnoses. Independence in mobility is a key factor in life satisfaction and contributes to maintaining the quality of life for the elderly and aging MWC user. The elderly frequently report having difficulty using their wheelchairs. Unfortunately, they are typically relegated to standard sling seat and back MWC. These standard MWCs introduce a slumped posture, are not adjustable, and place the user at disadvantaged positions to perform basic daily activities. The result often is added cost to the system in having to provide caregiver assistance or institutionalization. Ganesh and colleagues found that 61% of their sample of older adults reported difficulty with manual wheelchair propulsion, indicating that mobility devices provided for older adults may not be meeting their needs [91]. Trefler studied thirty persons, 60 years of age or older, who received individualized MWC and seating. Discomfort, poor positioning and mobility, and skin integrity were the most common issues reported in their standard issued wheelchairs. Participants who received individualized MWC found they had less difficulty independently propelling their wheelchairs and improved postural stability, which increased their ability to lean forward and reach. They reported a greater degree of satisfaction with their wheelchair technology and improved quality of life for social function and physical role as compared to a control group of individuals in standard issue wheelchairs [13].

This review paper addresses important issues for preserving function and mobility for elderly and aging individuals who use a MWC by presenting the current available evidence and recommendations. These include recommendations for reducing the mechanical loads and muscular demands through ergonomics, wheelchair selection and configuration, and environmental adaptations and personal factors related to increasing the capacity to handle the daily mobility demands. Each recommendation is supported by current research in each relevant area. While much of the research evidence put forth in this review were from the SCI population, they nonetheless apply to the general population who use MWC for daily mobility, particularly the elderly and aging MWC users.

This review also highlights the need for individualization of the wheelchair prescription process such that the characteristics of the wheelchair are matched with the functional capacity of the individual. It is important to note that while studies comparing different wheelchair technologies provide valuable information to guide clinical decision-making and wheelchair selection, the evidence will not always apply to all chairs within the same class or code, i.e. all wheelchairs are not equal even within the same category. What is important is that clinicians must identify the wheelchair characteristics that are crucial for each consumer and then identify the appropriate wheelchair that result in a fit that is specific and unique to a single individual user. The ability to order, modify or adjust the frame or components to achieve a final system that meets the medical and functional needs of the individual is the most important.

Research on demands during MWC use

The relatively high magnitudes, frequency of loads, and durations with daily wheelchair activities have been reported as the source of primary pain and dysfunction in persons who use

a MWC [92]. To prevent further loss of functional independence, it is imperative to find ways to reduce the strain and joint deterioration that may occur with MWC use. Evaluation of the mechanical load on the musculoskeletal system is important in understanding the mechanisms that may cause pain and pathology and guide recommendations in prevention. Measurement and computing technologies such as electromyography (EMG), motion sensors, force, and pressure transducers are required given the needed detail and accuracy for quantifying the physiology and biomechanics during wheelchair sitting, propulsion, transfers and raises, in both laboratory and more realistic settings over different conditions, and across a variety of target populations, including elderly and aging MWC users.

Simultaneous recording of muscle activity (EMG) using indwelling fine wire or surface electrodes allows detailed studies of the demands on the specific muscles or groups of muscles involved in manual wheelchair propulsion [37, 38, 93-98], transfers and raises [99-106], overhead activities [107], and sitting [108]. EMG recordings were used to show the reduction in muscle demands when using a power-assisted wheelchair in elderly MWC users [109].

Evaluation of the kinematics of the trunk and upper extremities during transfers [103, 105, 110], raises [102, 110] and overhead reaching [111] can identify movement patterns that predisposes the user to a greater risk for injury and guide clinical interventions, including older adults with disability [109, 112, 113]. Contoured or flat cushions provide a firm support surface for the pelvis instead of sling upholstery and immediately improve posture and upright alignment [114].

Determining the forces and moments experienced by the user during propulsion and related activities requires instrumented wheels [115-118] an ergometer [119], or platforms [120-122] to accurately measure three-dimensional reaction forces and moments on the hand during WCP, transfers, and raises. Instrumented handrim have been used in documenting the distribution of propulsive forces at different speeds and resistances [116, 123-128], identifying optimal wheelchair configuration [112, 129, 130], and examining the effectiveness of propulsion with different strengths [131-133]. Evaluation of the joint kinetics can identify excessive loading patterns that may predispose the user to injury during WCP, transfers, and weight-relief raises. To demonstrate the magnitude of loading at the shoulder, studies have reported the net joint forces and moments during wheelchair propulsion at various speeds and power output [124, 134, 135], on levels and ramps [118], and during exercise and fatigue states [136, 137], and elderly MWC users [112, 113, 127]. Cowan, in a study of wheelchair propulsion in older adults showed that surface type has a substantial impact on the biomechanics of wheelchair propulsion that magnifies the differences in the individual's functional capacity and wheelchair configuration [138].

Early studies on WCP documented that the higher rate of energy expenditure (33% greater than normal) attested to the increased arm work involved [139]. Metabolic energy measures have since been used to document the reduced energy demands of propelling ultra-light versus lightweight wheelchair [140] to document that alternative propulsion techniques and systems such as power assist rims reduce the energy demands of WCP [141-147], including in older adults with disability [109]; to show that lower wheelchair seat height improves efficiency [148, 149] and to determine which tires and tire pressure settings require the least effort during

propulsion [128, 150]. Energy expenditure recording also demonstrated that propelling in a side slope increases energy requirements [151] and that an individual's stroke pattern during WCP is related to efficiency [152-154].

Determining the seat interface pressure during sitting assists the selection of seat cushions [47, 51, 155-159] for pressure management and positioning in the elderly [156]. Tam et al. investigated the movement of the ischial tuberosities and the redistribution of interface pressure during manual wheelchair propulsion to gain insights into the etiology of decubitus ulcers [159]. They determined that the average interface pressure over the ischial tuberosity area was lower under dynamic wheelchair propulsion conditions. However, there is a concentration of high-pressure gradients around the peak pressure areas of the buttock [159, 160]. In determining the optimal design of seat support surface for the elderly, Breinza et al. used a dynamic pressure monitoring system to obtain pressure-time profiles from elderly adults subjects [156]. They determined that support surfaces designed using tissue stiffness criteria could provide loading conditions that minimize stress in load-bearing soft tissue and decrease risk of pressure ulcer development. Therefore, seat cushions with pressure relieving properties that are used appropriately are important in preventing pressure ulcer development in the elderly and aging MWC users [161].

The above research tools for assessing the demands during MWC use has led to the development of evidence-based guidelines for preserving mobility function for MWC users, including prescriptions for ergonomics, equipment selection, user-wheelchair interface (wheelchair seating), propulsion and transfer techniques, and exercise prescription [162, 163]. The Consortium for Spinal Cord Medicine organized by the Paralyzed Veteran's Association (PVA) developed a guideline "Preservation of Upper Limb Function Following Spinal Cord Injury: A Clinical Practice Guideline for Health-Care Professionals" based on most current scientific and professional information available [164]. A multidisciplinary panel of experts extensively debated the merit and evidence-based information supporting each of the recommendations. Most recently, the impact of the application of the PVA guideline in transfer skill training [165] and wheelchair setup, selection, propulsion biomechanics, pain, satisfaction with life, and participation [166] was evaluated clinically. The investigators determined that for those who were trained with the evidenced-based, structured education program improved the quality of transfers [165] and better skills on key wheelchair propulsion biomechanics [166]. Using the framework of the ICF, the recommendations put forth in the PVA clinical guideline provides a foundation for addressing key elements and strategies aimed at preserving mobility in persons who use a manual wheelchair as a chief mode of mobility. Many of the recommendations put forth in the guidelines apply to the elderly and aging MWC user in general regardless of specific diagnosis.

Ergonomics

Minimize the frequency of repetitive upper limb tasks and reduce the forces required to complete the task

Based on current ergonomic literature, repetitive performances of the tasks and high forces associated with each task place added demands on the upper extremities and have been implicated as risk factors for strain injury and/or pain during work-related activities

[167-169]. The demands on the upper extremities are dictated by the frequency of repetition of tasks and the forces required for completing the tasks. In particular, the most strenuous activities for manual wheelchair users are entering or leaving a car [170], ascending inclines [171], performing heavy lifting with arms [172], and propelling wheelchairs outdoors [171]. For the elderly and aging adults with diminished functional capacity, this is particularly challenging and can be problematic. During WCP, the frequency and forces can be minimized through equipment selection, particularly the use of properly sized equipment and the use of lighter weight wheelchairs [173-175]. Additionally, individualized adjustments to optimize the user-wheelchair interface, such as the amount of seat bucket, the seat to back angle, back height, rear wheel placement that promotes the most functional posture and balance [114, 176] should be adopted. Moreover, a lower frequency of transfers and overhead arm activity tasks can help prevent strain or injury, particularly in elderly and aging MWC users. Finally, the forces required to transfer into and out of the wheelchair can be reduced through optimal transfer mechanics during independent [177-180] and dependent transfers, and use of simple assistive technology, such as sliding transfer boards or mechanical lifts that is safe for both wheelchair user and the assistant [181, 182].

Minimize extreme or potentially injurious positions at the shoulder by avoiding extreme internal rotation and abduction

The classic position for impingement is when the arm is internally rotated, forward flexed, and abducted [183]. Internal rotation and abduction are common positions during WCP [94, 135, 149, 184-186] (especially when the wheelchair is too wide) and transfers [180]. Newsam et al. [187] indicated that the marked posterior plane with internal rotation position of the humerus at initial wheel contact places the greater tuberosity and supraspinatus tendon close to the acromion, increasing the potential for impingement. It is recommended that manual wheelchair users minimize extreme internal rotation and abduction during WCP through proper equipment selection (adjustable wheelchairs), appropriately sized wheelchairs, and individualized configuration (moving the wheel forward or up/down with an adjustable axle position in relation to the seat) and better upright sitting posture to improve shoulder mechanics. The extreme shoulder positions experienced during transfers into and out of the wheelchair can be reduced through optimal transfer mechanics and use of assistive technology [181, 182, 188], such as sliding transfer boards and mechanical lifts [188]. Assisted or dependent transfers that is safe for both wheelchair user and caregiver assistant [189] is recommended.

Equipment Selection

Recommend a customizable manual wheelchair. Use wheels and tires with the least rolling resistance

Manual wheelchairs are generally grouped into three categories: Standard frame (35 lbs. or more), a semi adjustable standard lightweight frame (30 to 35 lbs.), and an adjustable ultra-light frame (less than 30 lbs.). Adjustable frames typically offer more customization in seat widths, seat depth, back heights and seat heights, improving the user to wheelchair interface. Adjustability in frames allow the seat to floor height to be lower for foot propellers and allow for the rear wheel to be moved forward to decrease shoulder demands for those individuals using primarily their arms to self propel. Lighter chairs require less effort to propel, are

adjustable, and are made of stronger, higher-grade materials [173-175, 190-192]. Overall, highly adjustable rigid, lightweight chairs cost less to operate [193] because they last longer [191] and are more durable [192]. Additionally, use of caster wheels and tires that minimize the rolling resistance will minimize the forces during WCP [128, 194]. Propelling a lighter weight wheelchair was shown to be more efficient than propelling a standard wheelchair. The energy cost of propelling the lightweight chair at a specific velocity was 17% less than that of the standard, non-adjustable wheelchair. The greater efficiency of the lightweight wheelchair was attributed to differences in individualizing the wheelchair prescription and configuration in addition to the total mass of the device [127, 195]. Adjustable wheelchairs allow for different rear axle positions, wheel camber, seat angles, seat inclinations and back heights that are important factors influencing ride comfort and MWC mechanics. Cowan et al. examined the impact of surface type, wheelchair weight, and rear axle position on older adult propulsion biomechanics. They concluded that increased surface resistance decreases self-selected velocity and increases WCP peak forces. Increased weight (wheelchair, seating, and user) decreases self-selected velocity and increases WCP forces. Anterior axle positions were found to decrease WCP forces, especially on high carpet. The greatest reductions in WCP peak forces occurred in lighter chairs with anterior axle positions [127]. Beekman et al. [140] determined the energy cost of WCP in people with SCI, comparing 20-min self-selected propulsion on an outdoor track in a lightweight and ultra lightweight wheelchair by group - persons with paraplegia (n = 44) and tetraplegia (n = 33). Speed, distance travelled, and energy cost ($VO_2 = \text{mL/kg/m}$) were compared by wheelchair, group, and over time. In the ultra-light wheelchairs compared to the heavier chairs, speed and distance traveled were greater for both paraplegia and tetraplegia participants. Sawatzky et al., in comparing the rolling resistance differences of five commonly used wheelchair tires (three pneumatic and two solid) under four different tire pressures (100, 75, 50, and 25 of inflation), determined that solid tires ("no-more flats") had greater rolling resistance than all three pneumatic tires even when tires were underinflated to 25% of tire pressure [150]. Furthermore, energy expenditure measured during wheelchair propulsion showed that tire deflation significantly increased energy consumption at 50% of tire inflation. These findings are relevant to the elderly wheelchair user to decrease unnecessary demands on their already compromised arms and cardiovascular systems by having wheelchairs adjusted and components selected to maximize efficiency and minimize rolling resistance that minimize energy expenditure while meeting their mobility needs.

Optimize User–Wheelchair Interface for Propulsion and Function

Prescribe a custom configurable wheelchair

Individually configured wheelchairs have been important in preserving wheeled mobility function by providing the best fit to the individual for and energy efficient MWC propulsion, stable hands free sitting balance for ADL, prevention of pressure ulcers, and upper extremity function that help avoid fatigue and pain. Adjustable and individually configured wheelchair frames can address postural deformities such as posterior pelvic tilt and kyphosis, hip extension that promotes a slumped posture, and indirectly affects upper extremity reach and head posture. Standard frames are not adjustable in wheel position, seat to floor height or seat to back angle. Standard frames can accommodate limited aftermarket seating to address minor postural deformities. Wheelchair users who propel with their feet need a frame that has adjustability in

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seat slope or seat height to allow foot flat position on the ground. Those elderly, who propel with their feet only, need wheelchairs that have adjustability of seat height and do not require the adjustability of the axle forward. Some frames that have adjustability of the axle to move the rear wheel forward or up and down for upper extremity propulsion also have some adjustability of the seat slope to change the position of the body in space. The seat slope or backward seat angle positions where the hips is lower than the knees in such a way as to prevent the hips from sliding forward in the seat or tilting the seat to back angle in a manner to accommodate for a kyphotic, forward head posture; thus improving upright head position. A smaller seat-to- back angle can improve pelvic stabilization but can make transfers difficult. If an individual is active and independent in the home or community and is experiencing the effects of aging, lighter weight and adjustable frames can be individually configured to maximize function and comfort in their seating. The research and experience has shown that a wheelchair that is poorly matched to the individual, adversely affects potential activities and participation, lifestyle goals, health status and are costly [162]. In a systematic review of the literature for persons with Multiple Sclerosis (MS) and mobility assistive technology (MAT), manual wheelchairs (60%) have been reported as the most common MAT used by persons with MS [196, 197]. The quality of wheeled mobility devices recommended for persons with MS was inferior (less adjustable for the user) to that of devices issued to persons with SCI. Persons with MS may be issued a poorer quality (heavier and with limited options) MWC compared to those with SCI because clinicians anticipate the slow progression of this dynamic disease. Clinicians may view the use of a manual wheelchair as an intermediate step in the disease progression of MS to be followed by an increased reliance on a power device for mobility. Since many individuals obtain prescriptions for a manual wheelchair to alleviate some of their daily fatigue, they are marginal users or may not initially use the wheelchair as their primary means of mobility and are therefore issued a wheelchair with limited options. Ironically, this lower level, non-adjustable wheelchair may lead to an increase in the fatigue symptoms they are attempting to overcome because standard chairs are heavier and non-adjustable and, hence, require increased effort and energy expenditure [198]. Perks et al. reported that the average age of the marginal users surveyed was 48 years and the modal diagnosis was MS. Fifty-nine percent of the marginal users questioned felt that their wheelchairs were not adequate for their requirements. They had difficulty navigating within different environments and did not feel their wheelchairs met their mobility needs [199]. They were unable to maintain a functional speed of wheelchair propulsion when compared with a control group of persons with SCI and a group of persons without disability[200]. The higher energy requirement for obtaining functional mobility is a significant problem for those with MS, for whom fatigue is a major limiting factor. The reduced mobility caused by less adjustable heavier wheelchairs can be generalized to the elderly and aging population and are also associated with difficulty in ADL/ IADL and reduced quality of life.

Manual wheelchair users may also use foot propulsion for mobility. Persons with hemiplegia typically use their unaffected arm and leg for hemi propulsion; persons with an amputation will use a combination of both arms and one leg, or persons may use both arms and legs for conditions such as balance impairments, brain injury, Parkinson's disease or weakness or debilitation. Without a lower seat height position for foot propulsion, these users are either dependent in mobility or at risk for sliding out of the seat trying to reach the floor to push with

their feet. Many elderly individuals with multiple comorbidities such as cardiovascular disease, hypertension, arthritis, and peripheral neuropathies that affect their physical capacity propel with all 4 extremities for maximum benefit. The typical MWC user with hemiplegia propels their wheelchair using their unaffected arm and leg [201-205]. The seat height must be low enough and their pelvis stable on a supportive cushion to prevent sliding out of the seat in an attempt to use their leg for propulsion and steering [203]. Charbonneau confirmed that foot propelling backward up inclines, curb cuts, ramps was safer and more successful using quadriceps muscles than trying to propel in a forward direction [204]. In addition to hemiparesis, many people with stroke have cognitive, sensory, and perceptual deficits. These impairments can adversely affect the ability of a person with stroke to safely and functionally perform wheelchair skills in a timely manner with good motor planning and safety judgment. These impairments may also increase the risk of adverse events in the wheelchair. Therefore it is important that the person's MWC is best configured for seated postural stability and efficient and effective propulsion to facilitate successful function and mobility.

Promote an appropriate seated posture and stabilization relative to balance and stability needs

In the execution of daily tasks, constant adjustments and corrections are made to maintain sitting balance, demonstrating the inseparable connection between dynamic sitting posture and function. Sitting posture and balance are influenced by factors including age, type of disability, type of activities, and preexisting conditions. For the MWC user, seating and postural support can affect both WCP and transfers. A high backrest may be necessary to provide adequate trunk support, but it must allow for scapular movement during WCP. Aissaoui et al. (2001) [114] demonstrated that using a cushion with a contoured base improved pelvic stability and upper extremity reach. Harms et al. evaluated the effect of wheelchair design and comfort in 58 subjects and found conventional wheelchairs with soft hammock or sling seats and backs contributed to kyphotic postures and cause low back pain in both non-disabled and disabled persons [206]. (Figure 2a)

Slumped postures used to compensate for trunk instability during bimanual activities, may contribute to chronic fatigue and pain. Postures used to compensate for trunk instability during bimanual activities, may lead to negative biomechanical events that potentially contribute to chronic pain. It has been suggested that postural control is the most important factor in preventing and treating shoulder pain [207]. It is recommended that the pelvis should first be stabilized; using a cushion mounted on a firm surface to provide postural support as well as optimal pressure distribution and comfort. (Figure 2b) Anterior and lateral trunk support should be used if an individual is unable to maintain a stable posture when performing functional tasks. Adjustments should be made for those persons with a slouched posture through posterior stabilization of the pelvis in its most corrected posture; and accommodating the fixed kyphosis via back support shape and angle (e.g. Jay Back).

Redford studied seating the elderly and made the following recommendations. In a well-aligned seated posture, the head and neck will be vertical with the hips flexed to 100 degrees, the knees flexed to 90 degrees and the feet flat on the floor. Holden et al.[208]studied the seating needs of 46 elderly persons using force plates and video tape analysis and recommended a 9 degree

backward tilt of the seat. The seat inclination helped to maintain the ischium in the rear of the seat by blocking the pelvis from sliding forward. This pelvic stabilizing configuration incorporates 3 points of control, the back support, cushion and anterior pelvic positioning belt, providing passive postural support for the pelvis and lower trunk, and allows a maintained position of increased erectness even with muscle paralysis. This configuration produced less shoulder protraction; less head-forward position, greater humeral flexion, and greater vertical reach above the seat plane, and less posterior pelvic tilt than the conventional configuration. It produced a more vertical postural alignment and greater reach ability versus the standard factory setup wheelchairs.

Special wheelchair seating systems have been widely used in clinical practice to improve the sitting posture of persons who have spinal deformities, inability to sit without support and possibly prevent progression of the postural deformities. Hsieh et al. determined that wheelchair intervention significantly correlated with an improvement in anterior and posterior head tilt and horizontal eye gaze while seated in the wheelchair [209]. There are many types of special seating with different components prescribed for different needs [196, 210]. For persons with scoliosis, lateral trunk and hip supports provide three point support system needed for hands free trunk balance. Lateral trunk and hip supports have been demonstrated to reduce or correct the magnitude of a flexible deformity or accommodate to a fixed spinal deformity preventing further spinal collapse [197].

Minimize the distance and obstacles between the wheelchair and the transfer location prior to transferring

Independent transfers is known to be one of the most strenuous wheelchair-related activities [41, 170, 211-213] and is thought to be a major contributor to the development of upper limb pain and injuries [214]. Koontz et al. [180] performed a literature review and obtained expert opinion on the relevance and strength of the evidence concerning setup and transfer performance. The aspects of setup that experts felt were addressed to some degree included vertical transfer distance, transferring across a gap and position of the mobility device relative to target destination. There is a consensus among studies that transferring to a higher surface implies greater exertion of the upper limb.

For elderly wheelchair users who are very weak and have poor trunk balance, assisted or dependent transfer is recommended. If a dependent transfer is to be performed, the horizontally assisted lift and minimized distance between the wheelchair and the transfer location is also recommended to minimize loads on the lumbar spine of the lifter [215].

MWC Skills Training

Social participation in the elderly improved significantly following manual wheelchair acquisition [11, 216]. However not only inappropriate wheelchairs or seating affect the use of the wheelchair, compromising independence but lack of confidence and training also leads to ineffective use. Therefore, treatment strategies that facilitate effective wheelchair use are increasingly important. This is especially true for older adults who have been reported to more frequently lack independence using their wheelchair [217].

In order for individuals to effectively use their wheelchairs, they must possess a variety of wheelchair skills [218, 219]. Training to improve wheelchair skills is often used to promote an individual's ability to use the wheelchair. This study examined the effects of wheelchair skills training on confidence with using a manual wheelchair in 65 year and older individuals living in the community via a parallel group in a randomized controlled trial study design. The results provide evidence in support of two 1-hour wheelchair skills training (WSTP) sessions to improve confidence with using a manual wheelchair among older adults who are inexperienced manual wheelchair users [90].

Flexibility and resistance exercise

Incorporate flexibility exercises, (endurance) and resistance training into an overall adult fitness program. The training should be sufficient to maintain normal glenohumeral motion. The training should be individualized and progressive, should be of sufficient intensity to enhance strength and muscular endurance, and should provide stimulus to exercise the entire major muscle groups to pain free fatigue

For individuals who have neurologically intact shoulder musculature, programs for management of shoulder pain are quite similar to programs designed for persons without disability. These programs most often include rotator cuff strengthening, steroid injections, and modalities as indicated [220-223]. For persons who use a MWC, however, exercise programs for management of shoulder pain should include training of the larger thoracohumeral musculature in non-weight-bearing positions [37, 38]. In addition, stretching of the anterior structures of the shoulder joint is recommended for MWC users to counter the internally rotated posture of the shoulder that develops secondary to tightness in the anterior capsule and the sternal pectoralis major. For improved program adherence, exercise programs should be performed from the wheelchair, which may require modification of the exercise setup. For persons with shoulder weakness, shoulder exercise programs require a unique design as they may limit the amount of shoulder musculature available to strengthen. In addition, impaired grasp function in some individuals requires additional exercise modification for complete independence (e.g., wrist weights take the place of dumbbells and loops take the place of handles). Impaired balance may necessitate the use of chest straps and posturing devices attached to the backrest to maintain appropriate balance.

Conclusions

Most people modify their lifestyle as they age because of decreasing physical capacity. Pain and secondary conditions associated with being elderly and aging with disability further accelerates loss of function and independence resulting in a decline in mobility, the ability to participate in their social roles which affects their quality of life. Being elderly and/or aging with a disability has a significant impact on MWC use. There has been an abundance of research documenting the demands on the upper extremity muscles, energy costs and kinematics of self-propulsion and the effect of seated posture on function and mobility. These studies have been used to develop evidenced-based recommendations to minimize the pain and onset of secondary condition that are even more prevalent in the elderly and aging MWC user.

Although research demonstrates the positive impact of provision of customizable wheelchairs on the level of functional performance and on the quality of life of MWC users, elderly residents living in institutional settings have also demonstrated improvements in posture and functional mobility when provided with wheelchairs that were not standard and non adjustable[13]. However, it is common practice for the elderly and aging individual in these settings to be relegated to standard non adjustable wheelchairs. The consequences of poorly fitted equipment can cause an accelerated decline in function, pain and fatigue from poor posture, an increase in need for caregiver assistance or alternative mobility devices, such as powered scooters or wheelchairs, in order to maintain levels of independence in pain free mobility. Individualized configured manual wheelchairs and seating systems can change postural alignment that improves comfort by decreasing pain from poor posture, improves the ability and efficiency to self propel, prolonging mobility and endurance and preventing the development of secondary problems. An appropriate wheelchair and seating system provides a stable base for using upper and lower extremities for all mobility related activities of daily living and, most important, propelling a wheelchair to maintain independent functional mobility to maximize quality of life.

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Figure 1.
ICF model as applied to elderly and aging manual wheelchair users.

Figure 2. Elderly person sitting in: a) Sling seat and back on a standard wheelchair MWC b) Firm contoured seat base to correct pelvic obliquity, supporting pelvis in neutral alignment and a solid back support with a 95-degree open seat to back angle to facilitate an upright trunk posture.