Review Paper: Wheelchair Design and Its Influence on Physical Activity and Quality of Life Among Disabled Individuals

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ABSTRACT

Encouraging an active lifestyle is an essential part of successful rehabilitation programs, and the link between physical activity and quality of life (QOL) is well established among patients with mobility disorders. Biomechanical aspects of wheelchair design play an important role in physical activity and social participation of disabled individuals. This review focuses on key biomechanical features of wheeled mobility devices including propulsion methods, overuse injuries, assistive technologies, prevention of pressure ulcers, and tire and frame design. We briefly review the role of design modifications in increasing the physical activity and improvement of QOL among wheelchair-bound adults.

1. Introduction

According to the latest global reports on disability, more than one billion individuals, who nearly constitute 14% of the world population, live with a form of disability [1]. Studies also indicate that approximately 10% of these individuals have lower limb disabilities, and are dependent on manually propelled wheelchairs for ambulation and performing activities of daily living (ADLs). About 20 million of the disabled, however, do not have access to wheeled mobility devices [2]. Moreover, the prevalence of severe forms of disability, with considerable functional limitations, is estimated to be around 200 million worldwide and an alarming increasing trend has been highlighted by the recent global health statistics [1].

Injury is the number one public health problem in the USA, with a price tag of over $260 billion annually [3]. People with impaired mobility and balance, including lower limb amputees, those with spinal cord injuries, osteoarthritis, degenerative muscle and neurologic diseases are typical users of wheeled mobility devices. There is a growing body of evidence on the vital importance of physical activity among these individuals and having an active lifestyle is an essential part of successful rehabilitation programs for patients with ambulatory disabilities

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[4-6]. Furthermore, the adverse consequences of physical inactivity and the wide range of secondary complications among the disabled are well studied [7-10]. Many studies have reported how low physical activity exacerbates cardiovascular risk factors including hypertension [7, 9, 10], type-2 diabetes [11] and obesity [12].

In addition, evidence is accumulating on the association of a sedentary lifestyle and the increased risk of osteoporosis in people with physical disabilities [13, 14]. The link between physical inactivity and development of psychiatric disorders, particularly depression and stress, is also well established in this population [8]. Some studies have stated that lower physical activity might trigger the vicious cycle of less fitness and debilitating dependence in wheelchair dependent individuals [15-17].

The influence of physical activity on quality of life (QOL) and psychological well-being has been thoroughly investigated among those with mobility disorders [18-21]. Many studies have reported a significant positive association between QOL and higher levels of physical activity in these individuals [19, 22-24]. Fewer studies have, however, assessed the role of technological advances in wheelchair design in promoting QOL, level of participation and physical activity in those with lower limb disabilities [25-29].

Many aspects in wheelchair design affect the overall mobility efficiency and stability. Adapting all these features to the individual needs and preferences of a wide variety of users is a daunting task from a medical engineering perspective. Fortunately, there is a expanding body of research addressing these complex issues to provide wheelchair users with the best evidence-based design and optimize the fine-tuning of user wheelchair interface [26]. The current paper briefly reviews the important aspects of wheeled mobility devices that influence physical activity, participation and QOL in wheelchair-bound persons. This information is of great value to rehabilitation therapists who prescribe appropriate products for individuals in accordance with the latter's needs.

2. Methods

We extensively reviewed the published English literature after the year 2000, using the PubMed database. Different combinations of queries with the following keywords were used in PubMed; wheelchairs, physical activity, activities of daily living, disabled persons, amputees, paraplegia, quadriplegia, quality of life, social participation, cumulative trauma disorders and overuse injuries. A total of 77 relevant as well as original articles were finally selected and evaluated in detail for writing this narrative review.

3. Wheelchair Weight, Frame Materials and Propulsion Biomechanics

In the USA, wheelchair manufacturers must meet the American National Standards Institute/Rehabilitation Engineering Society of North America (ANSI/RESNA) standards before marketing their products. Wheelchair weight and the adjustable configurations can dramatically affect the biomechanics of propulsion and users' satisfaction [30, 31]. Wheelchairs are classified based on their weight and adjustability into standard or depot, lightweight and ultralight wheelchairs [32]. Chair weight has been reported to be a reason for non-use among older adults. Energy expenditure and kinematic measurements have been investigated in correlation with wheelchair weight and floor surface. Weight addition in the range of 5 to10 kg has not been shown to significantly affect propulsion kinematics on a tiled surface, yet weight-imposed differences might impact mobility over more fatiguing surfaces [30, 33].

According to some studies, wheelchair confined individuals have rated ultralight wheelchairs as more appropriate in providing a more comfortable ride due to superior ergonomic design [34]. Furthermore, some studies have observed a lack of interaction between axle position and weight, suggesting reduction of peak propulsion force regardless of the axel position. The optimal combination of lightest wheelchair possible and most anterior axle position tolerated by the disabled person could provide efficiency while maintaining stability [30].

Endurance, durability, mass and stability of wheelchairs are dependent on the frame materials used. Wheelchairs' durability and fatigue life have been the subject of rigorous investigations. Lightweight wheelchairs are typically made from steel, aluminum or a combination, while alloy steel, aluminum, titanium or composites are usually used to make ultralight wheelchairs. Studies indicate that frame material does not directly affect the wheelchair performance in durability standard tests, and design based on standard mechanical properties is more important [35]. Existing literature suggests that despite their higher price, ultralight wheelchairs are more cost-effective options compared with lightweight and depot wheelchairs due to their longer fatigue life [36]. In addition, the adjustable components of the ultralight wheelchairs make it more flexible to meet the users' needs [35].

4. Tire Type and Biomechanics

A section of investigators have compared the cost-effectiveness and biomechanics of solid and conventional pneumatic tires. Problems like low back pain are common implications of continuous shocks and vibration during rides, and could be managed with the help of the use of appropriate tire and tire pressure. Compared with the pneumatic tires, 'No-more flats' solid tires have no risk of puncture as their name suggests, yet have decreased spring, less shock absorbance quality and higher rolling resistance on particular surfaces. Evidence points out to the fact that the benefits of pneumatic tires could outweigh their maintenance cost and time [37]. The proper inflation of pneumatic tires must be monitored regularly to minimize energy expenditure, and facilitate higher levels of physical activity and participation. Studies have shown a significant increase in energy expenditure when 50% of the tire is deflated [38] and an additional 25% load is added if the tire pressure is below 50% [39].

5. Hand Rim Design and Propulsion Efficiency

Substantial multidisciplinary research has been dedicated to ergonomic modifications, configurations for optimal performance and mobility of manual wheelchairs in sports [40]. Complex combinations of biomechanical, physiological and ergonomic factors have been studied under controlled conditions to maximize propulsion efficiency and prevent complications of chronic wheelchair use [27, 41]. The correct functionality of the upper extremities and biomechanics of propulsion are matters of ongoing investigation [42].

Hand rims are circular tubes, usually made of metal or plastic, attached to the outer surface of the wheels with a smaller diameter, which individuals use to move the wheelchair forward. Despite high mechanical load and low efficiency, hand rim propulsion remains the most common form of wheelchair ambulation. A considerable amount of research, with huge potential ergonomic implications, has been dedicated to the hand rim design and its biomechanical aspects to optimize the propulsion efficiency and users' satisfaction [43]. Not surprisingly, an enhanced QOL was confirmed, following reduction of the physical strain of wheelchair propulsion, by recent studies [42].

With the advent of new technologies and creation of multidisciplinary fields, studying the detailed biomechanics of wheelchair propulsion has become more feasible and new avenues of performance-related investigation have opened up. Small hand rim size has been attributed to reduced mechanical efficiency, increased muscle contraction and greater pressure on the contact surface [44]. Use of flexible hand rims with specific ergonomic design has been reported to improve maneuverability and propulsion efficiency [45]. Other measures to improve the fitting of hand rim to fingers, including increasing rim diameter, have also been reported to decrease finger and wrist flexor activity and result in relief of upper extremity symptoms [46].

6. Overuse Injuries

A wheelchair confined life and long-term use of these devices for mobility could result in musculoskeletal problems. Upper body overuse injuries have been a focus of rehabilitation research and significant efforts have been made to address the prolonged imbalance of physical strain and propulsion mechanics [47-49]. To prevent upper extremity musculoskeletal pain, wheelchair dependent individuals may choose a more sedentary lifestyle and this could start a debilitating vicious cycle leading to further secondary complications [26, 50]. Some studies have reported wheelchair skills' training as a predictor of QOL due to its preventive role against overuse injuries [51]. There is also mounting evidence on improvement of confidence and community participation following wheelchair skills' training programs, particularly among inexperienced elderly adults [52, 53].

Repetitive strain injuries mostly affect shoulders and wrists, but back and neck muscles might get involved as well [48, 54, 55]. A variety of design modifications have been suggested to reduce the impact of repetitive tension on the upper limbs. Important, biomechanically studied modifications include use of different configurations for hand rim [44, 56], rear wheel angle and inclination [57] and seat position [58]. The additive effects of daily activities, repetitive strains and dose-response relationships in developing overuse injuries are issues of ongoing research [43, 59].

7. Alternative Propulsion Methods

Due to a high prevalence of overuse injuries and overwhelming consequent problems, many researchers have proposed other propulsion mechanisms to prevent repetitive strain of the upper extremities. Lever and crank-propelled wheelchairs are among the most studied alternative wheelchair ambulation methods. Some studies have observed the beneficial aspects of these alternative propulsion modes in terms of less straining, reduced shoulder muscular demand and more efficiency among the wheelchair using population [60]. Arm crank and lever-propelled wheeled mobility devices are more suitable on rough terrain and outdoor surfaces that are not proper for the conventional push rim wheelchairs and as a result their use in some developing countries like India are more frequent [60-62].

Hand bike is another alternative to the conventional, manually propelled wheelchairs. Longitudinal studies and multicenter randomized clinical trials have confirmed that regular hand cycling training has a positive influence on aerobic physical capacity and muscle strength, without reported shoulder pain [63-65].

8. Powered Wheelchairs and Assistive Technologies

To increase independence and QOL of persons with disabilities, various assistive technologies have been introduced, and rehabilitation professionals must update themselves on the available systems and their benefits [66]. Regardless of concerns over reduction in physical activity and subsequent secondary complications of a less active lifestyle, use of powered wheelchairs has certain benefits and indications. The dramatic technological advances in the past decade has revolutionized and diversified powered, wheeled mobility devices [67]. Power assisted wheelchairs provide for mobility of a less physiologically stressful kind and less energy expenditure during propulsion [68].

Assistive devices have so evolved that it allow persons with severe forms of physical disability to complete their activities of daily living and gain an acceptable level of independence; the most important examples include joystick, voice recognition systems and other computer user interface technologies [69]. Recent advancements in the field of powered wheelchair design has been revolutionized by the ever-growing research on joystick interface technologies, yet users might face driving difficulties if not appropriately trained [70].

Another advanced technology is the Tongue Drive System (TDS) that has proved successful in patients with high-level spinal cord injury. TDS is a wireless and wearable assistive device that translates specific tongue gestures into motor commands sent to the powered wheelchairs [71]. In the future, assistive technologies in the form of brain machine interface would enable the permanently disabled patients to gain more independence in steering wheelchairs using their brain signals and completing the activities of their daily lives [72].

Active participation in sports is of great therapeutic value for disabled individuals and that is why attempts have been made to optimize wheelchair design and configuration for disabled athletes. The ever-growing need of professional athletes has been a driving force for innovation and technological advances to address the biomechanical aspects of wheeled mobility devices [73].

Modifications of wheelchair design have not remained confined to court sports but have also extended to the realm of water sports such as swimming. Considering the benefits of aqua therapy among disabled individuals, various patented wheelchairs and personal floatation devices have been introduced to encourage a more intensive participation in water sports even for patients with severe physical or mental disability [74, 75]. The need for a safe and reliable floating mechanism should, however, be addressed to protect against potential drowning or other water-related accidents.

Currently, it should be emphasized that very few individuals have access to these sophisticated and expensive technologies, and insurance companies in many countries do not cover them. Since recent studies have highlighted the facets of increased sense of self-esteem, greater independence and improved mobility among wheelchair bound individuals, analyses concerning cost-effectiveness should be conducted to further elucidate the costs and benefits of these technologies [76].

9. Preventing the Development of Pressure Ulcers

Prolonged sitting in wheeled mobility devices could lead to leg edema, tissue ischemia and development of pressure ulcers. These conditions highlight the importance of designing optimal support surfaces and cushions for wheelchairs. Patients with spinal cord injuries and disabled victims of chemical warfare who are more prone to neuropathy are at particular risk of developing pressure ulcers [77]. A bioengineering challenge is adaptation to individual differences in anatomy, and the postural and ischemic tissue changes following prolonged sitting [78].

According to recent reviews, the current literature regarding the most cost-effective wheelchair cushioning is inconsistent and further randomized trials are required to address this issue [79]. An assistive technology added in recent years is the passive standing option in some of these wheelchairs that have been documented to be effective in decreasing seating pressure and formation of pressure ulcers, and preventing osteoporosis and loss of muscular tone, thereby playing a positive role in the improvement of QOL of the physically disabled [80].

10. Conclusion

Modifications in wheelchair design and biomechanics could play a crucial role in promoting physical activity, QOL and level of participation among physically disabled individuals. Further research is necessary on cost-effectiveness of advanced design features, interventions to prevent overuse injuries and strategies to address the secondary complications of a sedentary lifestyle.

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Conflict of Interest

The authors had no conflicting interests, financial or otherwise.

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