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Wheelchair design for patients with spinal cord injuries

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ABSTRACT

Wheelchairs are the most common means of transportation for people with spinal cord injury (SCI). The needs, requirements, functional capabilities and personal preferences of the SCI patient should be clarified in order to obtain a wheelchair that will satisfactorily meet its particularities and will enjoy maximum comfort. The purpose of this study is to review the designs of wheelchairs used in the rehabilitation of patients with SCI. In the PUBMED electronic database, a search was performed with the use of the following keywords: "wheelchair" AND "spinal cord injury" AND "design". Inclusion criteria were studies evaluating wheelchair design in patients with SCI. The search revealed 573 papers. After checking titles and excluding papers, 48 studies were left for the present review. The proper design of wheelchair is vital to the quality of life of SCI patient. The design characteristics of the seat, the backrest, the wheels, the footrests, the cushions and other accessories may help SCI patients increase their independence and functionality and prevent from pressure ulcers.

Key Words: Orthotics, Wheelchair, Spinal Cord Injury

Introduction

Patients with spinal cord injury (SCI) suffer from a loss of mobility and sensation below the level of the injury. Some patients with incomplete injury below T12 have the ability to mobilize independently and self-care indoors and / or outdoors. However, in many cases, independent mobilization is impossible as the SCI causes problems that significantly affect patients' functionality. Their functional outcome depends on many factors such as the age of the patient, the level of the lesion, the type of lesion (complete or incomplete), the maintaining motor and sensation function, the body type, etc. The most important of these patients' problems are severe lack of mobility, loss of balance, spasticity as well as chronic pain and increased fatigue. These are the most important factors that lead patients to become partially or completely dependent on the use of wheelchair for travel and performing functional activities, as they have difficulty or are unable to move comfortably, easily and without assistance.

Wheelchairs are the most common means of transportation for people with SCI. The first wheeled device is found in China and Greece around the 6th century BC. Later, around 525 AD, the first wheelchairs for people transportation appear in Greek and Chinese works of art. In 1655, Stephen Farfler, a paraplegic

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watchmaker, made a self-promoted three-wheeled chair. In 1783, John Dawson in Bath, England, invented a wheelchair with two large wheels at the rear and a small wheel at the front, surpassing all other wheelchairs invented by the early 19th century. In 1900, the first radial wheels were added to wheelchairs. In 1916 the first motorized wheelchair was built in London. In 1933, the first folding, lightweight steel wheelchair was invented by Harry Jennings and Herbert Everest who had broken his back in an accident [1-2]. Since then, the evolution of technology and the seasonal trends have contributed to the construction of wheelchairs from different materials and different designs in order to meet different needs [3].

Wheelchair-dependent SCI patients use the power and function of their upper limbs for the manual push of the wheelchair and the performance of functional activities such as moving from their chair and movement of paralyzed body areas to avoid pressure ulcers [4]. Transportation is necessary daily as patients have to move to and from the bed, bathtub, toilet, car seat, etc. They are one of the most important and determining factors for community involvement and quality of life [5]. The number of daily transports varies widely, with some studies reporting a low average of 8 transfers per day, others estimating numbers that are closer to 20 transfers per day. Taking all these into consideration, the identification of the most suitable wheelchair is a difficult process and must be performed by the rehabilitation team. More than 55% of wheelchair has been found to be inappropriate for SCI patients [6]. The needs, requirements, functional capabilities and personal preferences of the SCI patient should be clarified in order to obtain a wheelchair that will satisfactorily meet its particularities and will enjoy maximum comfort.

The purpose of this study is to review the designs of wheelchairs used in the rehabilitation of patients with SCI.

Materials and Methods

In the PUBMED electronic database, a search was performed with the use of the following keywords: "wheelchair" AND "spinal cord injury" AND "design". Inclusion criteria were studies evaluating wheelchair design in patients with SCI.

Results

The search revealed 573 papers. After checking titles, 507 articles were rejected. Among the 67 publications evaluated, 18 were excluded as they did not mention wheelchair design or did not involve SCI patients, leaving finally 48 studies for the present review.

Goals of the wheelchair design

Choosing the right wheelchair is of paramount importance, as the right type provides every possible facility in the daily life of SCI patients. The wheelchair should be designed in a way that it can be used easily and safely by SCI patients providing comfort, stability and ergonomics. It should be flexible and easy to move both indoors and outdoors or at the patient's workplace. Additional goals include the possibility of adjusting the individual sections, the installation of removable covers to be washed and the use of ecological and recyclable materials [7]. The right choice of wheelchair makes the SCI patient more autonomous, sometimes relieves him of the need to rely on other people and increases his engagement with activities [8].

Wheelchair design characteristics

Seat

A proper wheelchair should provide a comfortable seat, good support for the back and the entire musculoskeletal system. This also helps in better breathing, easier swallowing and reducing pain along with the prevention of pressure ulcers [9-10]. The seat must be detachable from the main frame in order to be washed or cleaned [11]. Standard seat sizes are not suitable for every person and every type of disability. The seat of the wheelchair should be designed in order to allow ventilation of the patient's body, easy access, the possibility of aligning the backrest to allow physical therapy, the folding of the seat for easy transport and easy storage. It is important to calculate correctly [12-13]:

- The width of the seat, as it should be spacious for the hips, but not so spacious for the hands to reach the wheels.
- The depth of the seat should prevent lower limb vasoconstriction.
- The height of the seat should be adjusted to the body type of each patient to offer support and freedom. A lower seat position has been associated with

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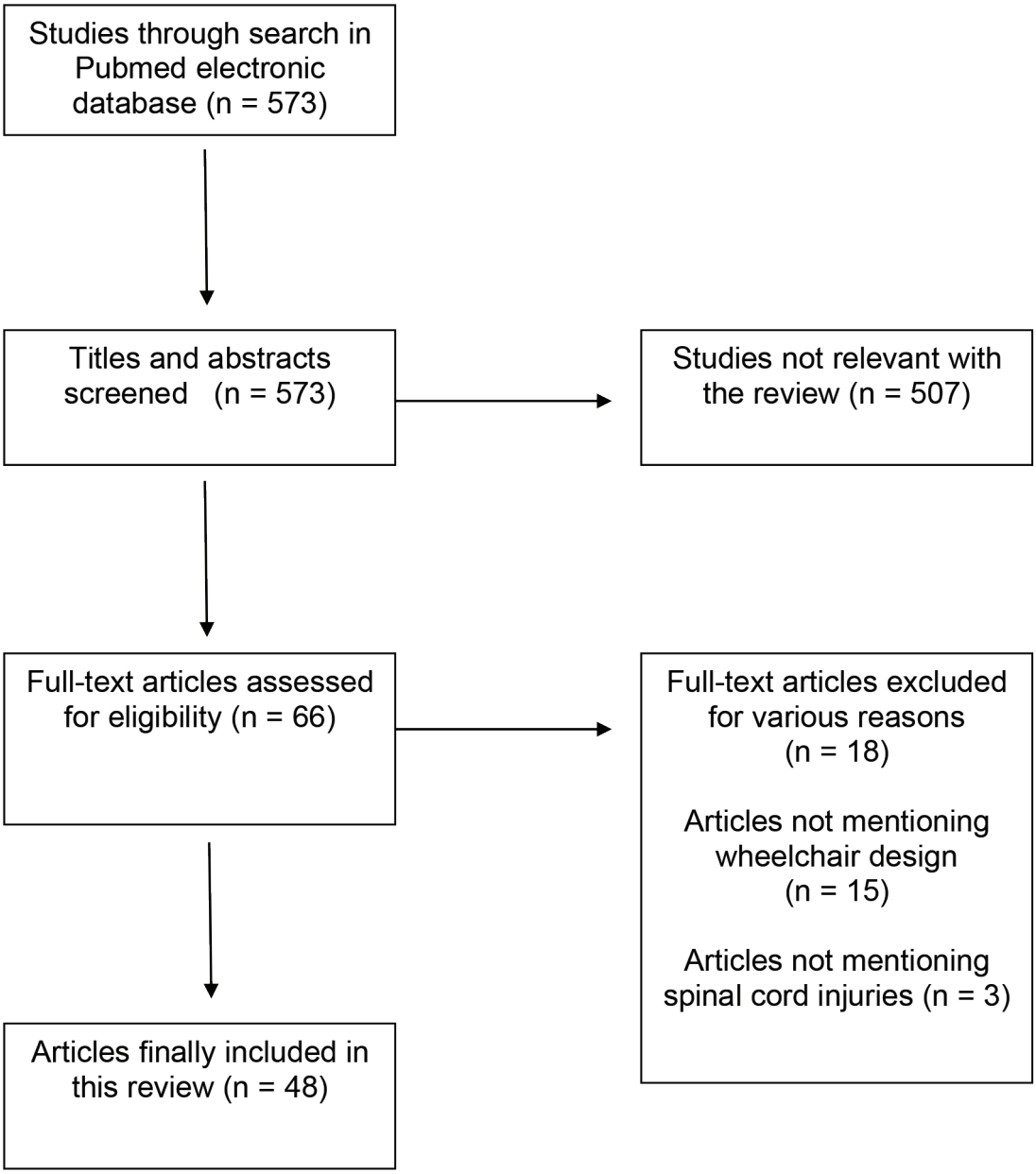
Fig. 1 Study Flowchart.



greater upper limb motions

Adding weight to the wheelchair can affect stability, and therefore packages or backpacks ideally should be located underneath the seat of the chair [14].

Backrest

The wheelchair backrest is manufactured by a flexible material stretched between the two side frames which are fixed with respect to the seat. The backrest should be high enough to support the spinal curves without inhibiting motion, yet not so low that the scapulae can hang over the back of the wheelchair and cause discomfort [7, 15]. A right detachable backrest may improve upright posture, functionality and wheelchair propulsion skills [16-17]. Changing wheelchair tilt with an inclinable backrest may be beneficial in relieving the pressure at ischial tuberosities and sacrum, by changing the intensity and direction of skin pressure,

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providing protection from pressure ulcers [18-21].

Footrests

The footrests are an essential and integral part of a wheelchair as they provide support to the feet and create a sense of security for SCI patients as they themselves may not control their feet. The type and length of the footrest must be determined by the type of use. In any case, the height of the feet should prevent the legs from hanging down and on the other hand it should not push upwards to create a slope in the pelvic area [22].

Cushions

Protective pads and soft, flexible cushions are important for relieving pressure and the prevention of pressure injuries [23-27].Cushions are also important for stabilizing the pelvis and providing postural support [28]. Therefore, patients with SCI should use an appropriate, regularly cleaned cushion for their wheelchairs [29].

Wheels and tires

The basic type of wheelchair has two 24-inch diameter rear wheels and two 8 inch caster wheels in the front. The tires may be pneumatic, semi-pneumatic, or solid. Solid rubber tires are suitable for use on smooth surface and indoors. The semi-pneumatic and pneumatic tires are more suitable for rough surfaces and outdoor use as they provide shock absorption. Tire pressure affects wheelchair durability. Pneumatic tires provide a smoother ride and their shock absorber action may increase the life duration of a wheelchair under proper inflation [30-31].

Wheelchair accessories

The use of the table is essential as it allows the patient to dine, read and more. The table should not obstruct the patient with its position, so it should be folded or detachable. Ergonomic hand rims improve SCI patients' symptoms, functionality and independence [32]. Wheelchair arms should be light and detachable, providing support and facilitating the transfer into and from the wheelchair. The rear axle should be moved forward incrementally, provided the wheelchair user feels stable [14, 33]. Wheelchair rear-suspension systems may improve wheelchair mobility by providing comfort at higher speeds, and by minimizing the seat forces and head accelerations experienced by the SCI patients [34].

Types of wheelchair

Wheelchairs are classified into the following types: Manual wheelchairs (simple type wheelchairs, special type wheelchairs), electric wheelchairs, lightweight wheelchairs, scooters, standing power wheelchairs, bath-toilet wheelchairs and sea wheelchairs

The standard manual wheelchair has two side frames linked by a cross-bar that is pivoted about its intersection and a flexible and foldable seat and backrest, two large driving wheels at the rear, and two caster wheels at the front. Manual wheelchairs may be used by patients with paraplegia who have the ability to move the upper limbs or by patients who use the wheelchair occasionally [35-36]. Repairs completed on the wheels and casters were the most frequent repairs to manual wheelchairs [37].

Simple-type wheelchairs

Simple wheelchairs may be used at almost every type of disability. They include (a) wheelchairs with large rear wheels (intended for outdoor use), (b) wheelchairs with medium rear wheels (suitable for both outdoor and indoor), (c) wheelchairs with small rear wheels (recommended only for indoors) and (d) special types [38-39].

The first type is a wheelchair with two large wheels at the rear and two smaller ones at the front. It is used outdoors as it is more flexible, easy to use and offers the patient the opportunity to put it at an angle, so that he can climb stairs and pass over obstacles. Many times a second, auxiliary frame is applied to the main frame of the wheelchair, which smoothens the weight distribution and prevents the overturning of the wheelchair [39]. Various anti-rollback devices may assist manual wheelchair users to ascend ramps and inclines [40].

The second type is a wheelchair with two medium wheels at the rear and two smaller ones at the front. These wheelchairs are ideal for movement inside or outside the house, but always with the help of an attendant since the patient cannot move alone. Moving around a house is easier, but it puts a lot of restrictions

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on transportation and is not practical, especially when it comes to obstacles [39].

The third type is a wheelchair with 4 small identical wheels at the rear and at the front. These wheelchairs are ideal for indoor use only, as the size of the rear wheel does not allow them to move outdoors. Patients with this type of wheelchair need the help of an attendant in order to move, while there are usually no extra amenities. Their big advantage, however, is their extremely small width, which allows them to fit even in very narrow spaces [39].

Special categories of simple wheelchairs may offer greater comforts and include folding wheelchairs, wheelchairs with braking assistance, wheelchairs with separated backrest, recliner wheelchairs, wheelchairs with retractable sides, wheelchairs with retractable footrests [41].

Special-type wheelchairs

They are wheelchairs for specialized uses, specially designed for SCI patients with sports disabilities, who have lower backrests and extra features, mainly to offer safety and balance during use. Most of them have a reclining backrest, reinforced mechanisms and many practical adjustments that ensure complete comfort and cover every need. They are reinforced with large inflatable rear wheels, inflatable front wheels, folding or fixed frame, with brakes, adjustable backrest and seat, removable and adjustable footrests and push handles [39].

Electric wheelchairs

Electric wheelchairs are designed to be used by SCI patients who cannot move wheelchairs manually or who would have to waste too much energy doing so. This involves patients with very limited mobility of the upper extremities and especially in cases of quadriplegia and SCI above C7 level. It moves with two motors with battery lithium 12V, speed up to 10 km/hr and carrying capacity up to 100 kg [42-43].

The electric wheelchair has a high backrest, with specialized head or hand controls, with front wheels, with detachable legs, either with high support in the gastrocnemius area or with support at the height of the heel, with a seat and with cushions [43-44]. Electric wheelchairs allow tilt and recline maneuvers, redistributing loads away from coccyx and ischium, preventing ulcers [45]. However, using a motorized wheelchair has certain disadvantages, such as potential weight gain, increased rate of electrical failures and repairs, deconditioning and increased cost. Electric wheelchairs are also associated with decreased transportability and increased maintenance [6, 46-48].

Lightweight wheelchair

The standard lightweight wheelchairs are manufactured by most companies as a variant of the standard models. They are wheelchairs with a light frame and accessories that contributes to easy movement. They are wheeled with brakes, manufactured by light alloy frame (aluminum, titanium or magnesium) with adjustable center of gravity, angulated seat and backrest, removable 24-inch rear wheels and footrests, swinging detachable footrests and with high support in the gastrocnemius area. Its maximum weight is up to 12 kg without rear wheels, about the 2/3 of the standard model. Lightweight wheelchairs, generally preferred by patients with paraplegia, they may be easily placed in cars and contribute to increased mobility and freedom of movement, independence and enhanced socialization [49].

The sports wheelchair is a very lightweight wheelchair, with a weight less than 12.5 kg and is designed for intense use in sports activities with wheelchairs. Its frame is disassembled and stored in a special box [50]. Development of this lightweight, high-performance, sports chair has led to racing among wheelchair users and has made playing sports from wheelchairs practical and enjoyable. These wheelchairs have also been found useful in non-competitive recreation, such as camping and mountain climbing. Recently, ultralight wheelchairs have been manufactured by titanium and aluminum, improving the efficiency of propulsion [30, 44].

Scooters

They are designed for SCI patients with incomplete lesions who can walk, but also who have very good control of the body. They are dynamic, electric-powered systems, with four or three wheels, folding seat and they are driven by steering wheel. Their main feature is their rotating properties, facilitating entrance and

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exit of rooms [51].

Standing power wheelchair

The standing power wheelchair is an important aid that helps patients with incomplete SCI and inability to walk to stand in an upright position with the help of a controller by simply pressing a button without the need for adjustments or external assistance. These wheelchairs offer the user the ability to automatically–and safely–move from a sitting position into a standing one [52].

Bathroom - Toilet wheelchair

It facilitates SCI patients as it has a toilet bowl, soft seat, removable or folding legs, solid wheels, lifting and fixed arms, brakes on the rear wheels and in some cases a special waterproof lining suitable for bathing.

Sea wheelchairs

They are specially designed wheelchairs for easy rolling in the sand, waterproof and durable.

Dangers from improper wheelchair designs

The right wheelchair can help prevent injuries related to balance and instability. There are possible dangers from wheelchairs which are not properly fitted in SCI patients. The pelvis and spine can be misplaced in the wheelchair and at a later stage there is an increased chance of serious health problems (such as fatigue, pain, infections, tissue damage, respiratory problems and permanent injuries). Simple wheelchairs provide limited options and do not effectively serve everyone's personal needs. Heavy wheelchairs are not suitable for all body types. It may burden the SCI patient and keep him / her away from activities, locations and people. Proper position of the SCI patient in the wheelchair is important, so as not to create pressure ulcers and deformations, and the patient to gain maximum stability for independent activity [53].

Conclusions

The choice of the proper wheelchair is of paramount importance in SCI patients, as the right type provides every possible facility in the daily life. The wheelchair should be designed in a way that it can be used easily and safely by SCI patients providing comfort, stability and ergonomics. The right type of wheelchair makes the SCI patient more independent, sometimes relieves him of the need to rely on other people and increases his engagement with activities.

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