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Robotic Rehabilitation of Spinal Cord Injury Individual

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SUMMARY

Background. Various types of systems have been used for rehabilitation of Spinal cord injury (SCI) individuals, including mechanical orthoses, functional electrical stimulation (FES), hybrid system and robotic devices. Although, the use of robotic systems for rehabilitation of SCI subjects is increasing, there is not enough evidence to determine the positive and side effects of this system. Therefore, the aim of this review article is to find some evidences to support the influence of use of this system on the performance of the subjects. Furthermore, it was aimed to find the difference between the performances of paraplegic subjects while walking with robotic devices.

Material and methods. An electronic search was done based on PubMed, Embase, Ebsco, and ISI Web of Knowledge to extract the data from 1970 to 2012. The quality of the research studies was evaluated by use of Black and Down tool.

Results. Although 250 papers have been found based on the selected key words, finally 10 papers have been selected for final analysis. There were only two clinical trials done in this regard. There are some improvements which were reported to body function and activities follow the use of robotic device.

Conclusions. 1. Although various types of orthotic systems have been developed for paraplegic subjects for walking and rehabilitation, there is not enough research in this regard. 2. It is not easy to determine the therapeutic influence of robotic orthosis on the health status of paraplegic subjects. 3. There is a huge gap for a randomized clinical trial research to determine the effect of robotic system on the health status of the SCI subjects.

Key words: Spinal cord injury, rehabilitation, robotic, performance

BACKGROUND

Spinal cord injury is damage to spinal cord that results in loss of function, mobility and sensation below the level of injury [1]. This disorder is characterized based on amount of functions remained below the level of injury. The incidence of SCI varies between countries. It has been reported that between 12.7 and 57 new subjects get this problem per million of population each year [2-9]. In the USA it has been estimated that there are 183,000 to 230,000 individuals with SCI, compared with 40,000 in UK [9,1].

Unfortunately most of the subjects miss their abilities to stand and walk and use orthosis and wheelchair to ambulate from place to place. Although paraplegic subjects have confirmed some problems such as slow walking speed, high energy consumption, fear of falling, and too much force applied on upper limb during walking, it has been mentioned that walking and standing with orthosis influences bone mineral density (BMD), improves cardiovascular and digestive system functions, improves bladder function and influences the physiological and psychological health of SCI subjects[10-12,7-14]. Therefore, most of the clinicians advice the subjects to use orthosis instead of wheelchair for their ambulation.

Various kinds of orthoses have been designed to enable SCI individuals to stand and walk. Some mechanical orthoses such as double knee ankle foot orthosis (KAFO), Hip Guidance orthosis (HGO), Louisiana Reciprocal gait orthosis (LSU RGO), Advanced reciprocal gait orthosis (ARGO), Hip knee ankle linkage orthosis (HALO), and Isocentric reciprocal gait orthosis (IRGO), have been designed in this regard [15-17]. However, slow walking speed, high energy consumption during walking and the force applied on upper limb during walking are the main issues mentioned by paraplegic subjects[13,14]. Some external systems which have used pneumatic and hydraulic source of powers have been designed for paraplegic subjects [18-20]. Functional electrical stimulation is the other method to improve the performance of the subjects during standing and walking, which is the application of external power electrical stimulation to paralyzed muscles to restore their functions [21].

Improved standing and walking performance of SCI subjects has been attempted by integrating FES system with mechanical orthoses which are typically refereed as hybrid orthosis. Most of researchers have tried to increase the performance of subjects by putting knee flexion during swing phase, hip extensor force in stance phase, however there is not too much difference between the performance of subjects walking with mechanical and hybrid orthoses [22-24].

The use of robotic system for rehabilitation of SCI individual is a new developing method begun in earliest with development of MIT Manus. Since that time some of research groups and several companies developing robotic movement therapy for SCI subjects. Driven gait orthosis was the first system used with weight support training during walking of the subjects on a treadmill [25]. The system consists of a lower limb interface that attached to the treadmill frame and also with a body weight support system. This system has been shown to be effective in increasing the abilities of incomplete SCI subjects to walk independently [25]. The other robotic rehabilitation systems used for paraplegic subjects are lockomat developed by Hocoma and mechanized cart trainer with a crank and rocker systems. Some portable orthoses like Mina orthosis, prewalk and Berkley systems have been designed for paraplegic subjects in order to increase the efficiency of orthosis while walking [26].

It has been shown that rehabilitation of the neurological injury subjects depends upon three principle of motor learning including practice, specificity and effort, which emphasis that SCI individuals need to maintain a high degree of participation and involvement to facilitate motor learning [27]. Recent studies in subjects without SCI cleared that the EMG activities of the hip joint and trunk decreases follow the use of assistance to leg. The EMG activities of the leg and hip joint muscles depend mostly on the passive force used to progressive the ankle and hip joints during treadmill walking [27].

There is no doubt that the use of robotic rehabilitation therapy reduces the treatment cost and facilitates the rehabilitation programme. However there is not enough evidence to support the drawbacks and advantages of this system in rehabilitation of SCI. It has been mentioned by some researchers that the trapeutic benefits of robotic therapy are small [27]. In contrast other mentioned that the abilities of incomplete SCI subjects improved significantly [28, 27]. There are some important questions in this regard which need to be answered to support the efficiency of this system including:

Is there any differences between the outcome of rehabilitation of SCI subjects manually or by use of robotic orthosis

How much is the benefits of robotic therapy technology for SCI subjects

Is there any significant difference between the performance of paraplegic subjects while walking with robotic and mechanical devices

Therefore, the aim of this review article was to answer to aforementioned questions based on the relevant literature.

MATERIAL AND METHOD

An electronic search was done in some data bases such as, PubMed, Embase, Ebsco, Google scholar and ISI web of knowledge to extract the data from 1970 to 2012. Some key words such as orthosis, spinal cord injury, paraplegic, robotic orthosis, benefits of rehabilitation were used to search in the mentioned data bases. The abstracts and titles of each individual study were assessed by the author. The first step was to select the relevant articles based on whether abstract and title addressed the research question of interest. The second selection was done based on the following criteria:

- The study be published in English
- SCI subjects were used for analysis
- Subjects used robotic orthosis or robotic rehabilitation systems

Excluded studies include

- Studies used hybrid orthoses
- Studies used functional electrical stimulation
- Studies focused on the mechanical devices

Assessing the quality of research studies

The quality of the methodology of the research studies was assessed using the Down and Black tool. The reliability and validity of this test is acceptable to be used in this regard [29]. The author evaluated the quality score of the methodology of each research study. This tool consists of 27 questions divided into four categories including: reporting, external validity, internal validity (bias), internal validity (confounding). This tool ranged from 0 to 28, with a higher score indicating higher methodological quality [29].

Tab. 1. The results of studies of robotic rehabilitation used for SCI subjects

Research study	Level of evidence	Number of subjects	Level of lesion	Time after injury	Type of orthosis	Results	Quality assessment (out of 27)
Ming et al	1	10	C3-T10	1.3-13.5	Driver robotic with and without resistance. Over ground walking velocity after 4 and 8 weeks of training was recorded	It was feasible to control the stride length by adjusting the walker movement. Significant improvement in walking speed and balance was seen after robotic training system. No significant difference between the performance of subjects in using robotic system with resistance or assistance. However resistance training was more effective for higher functional patients.	25
Emken et al	5	6	C5-T4	4-15 (year)	Body weight support with treadmill. EMG activity of the leg muscles and kinematics of the joint were detected	Overall the kinematic pattern of the leg joint was the same in walking with and without support. The variability in a system to change step length is important.	25
Israel et al	5	12	C3-T10	1-18	Robotic and therapist assisted walking was evaluated. Metabolic cost and EMG data were collected by standing and stepping on treadmill with therapist or robotic assistance.	Metabolic cost and EMG activity were significantly lower with robotic than with therapy. It is important to minimize the stabilization provided by a passive structure.	24
Kagawa and Uno	2	1	No data	No data	Powered Assist Locomotor orthosis	No data	12

The level of evidence was determined based on key research designed scored from 1 to 5 as 1, 2, 3, 4, and 5 which are randomized control trials, prospective controlled trial, case control, pre post and observational or clinical consequence.

RESULTS

Based on the recommended key words, 250 papers have been found. The title and abstract of the papers were evaluated by the author. In this stage, 100 papers have been selected. Finally 10 papers have been selected based on the mentioned criteria.

Robotic orthoses used for paraplegic subjects include:

- Cable driven robotic gait orthosis with resistance force [30]
- Driven gait orthosis with pneumatic exoskeleton leg [31]
- Driven gait orthosis lockomat PRO
- Moon walker exoskeleton [32]
- Berkley exoskeleton [33,34]
- Wearable power assisted locomotor [35]
- Mina robotic orthosis [26]

QUALITY ASSESSMENT RESULTS

There were two clinical trial research done in this regard. Most of the research was case study or modeling. The quality of introduction part of the papers was acceptable. However their external and internal validity were poor. The results of the quality assessment are shown in Table 1.

DISCUSSION

Most spinal cord injury subjects relay on wheelchair to transport themselves from a place to place. However, they have being encouraged to walk with orthosis to improve their physical and physiological health. Various types of orthosis, mechanical and robotic have been developed to improve their performance. There are two main approaches regarding using orthosis with various power sources (no power, pneumatic, actuator and robotic) including transportation and therapeutic benefits. The results of various research studies showed that walking speed, the magnitude of energy consumption during walking are not comparable with that of transportation with wheelchair [36,12,37,13,17]. Therefore, most of the researchers have tried to improve the orthoses and robotic systems for therapeutic purposes. However, it is not cleared whether robotic systems add more therapeutic benefits than available orthoses or manually therapeutic methods. Therefore, it was aimed to find the benefits, the difference between the mentioned methods based on the available studies in the literature.

There are not too many studies on the robotic orthosis designed for paraplegic subjects. Most of the

Tab. 2. The results of review article assessment published on rehabilitation of SCI

Research study	Level of evidence	Number of papers reviewed	Quality assessment	Results
Swinnen et al	5	2 randomized control trial 4 pre-experimental trials	25	There are some improvements reported in body functions and activities; however, it is difficult to have a clear conclusion due to sample size of the research and methodological flaws
Jailani et al	5	No information	20	The use of FES and hybrid device for SCI mobility is too limited. Therefore more research and development must be done in this regard.
Herr	5	No information	10	The limitations of various robotic devices were discussed. There is no information regarding the performance of handicapped subjects using these orthoses. Further improvements in design of these orthoses were discussed.
Reinkensmeyer et al	5	No information	10	It is controversial whether using a robotic device improves the performance of the subjects or not. Further research is needed to determine whether compliant robotic devices improve the goals of rehabilitation or not.
Lünenburger et al	5	No information	10	Although it has been concluded that rehabilitation robotics offer an open platform for implementation of advanced technologies which provide training for patients, the authors provide no evidence to support their claim.

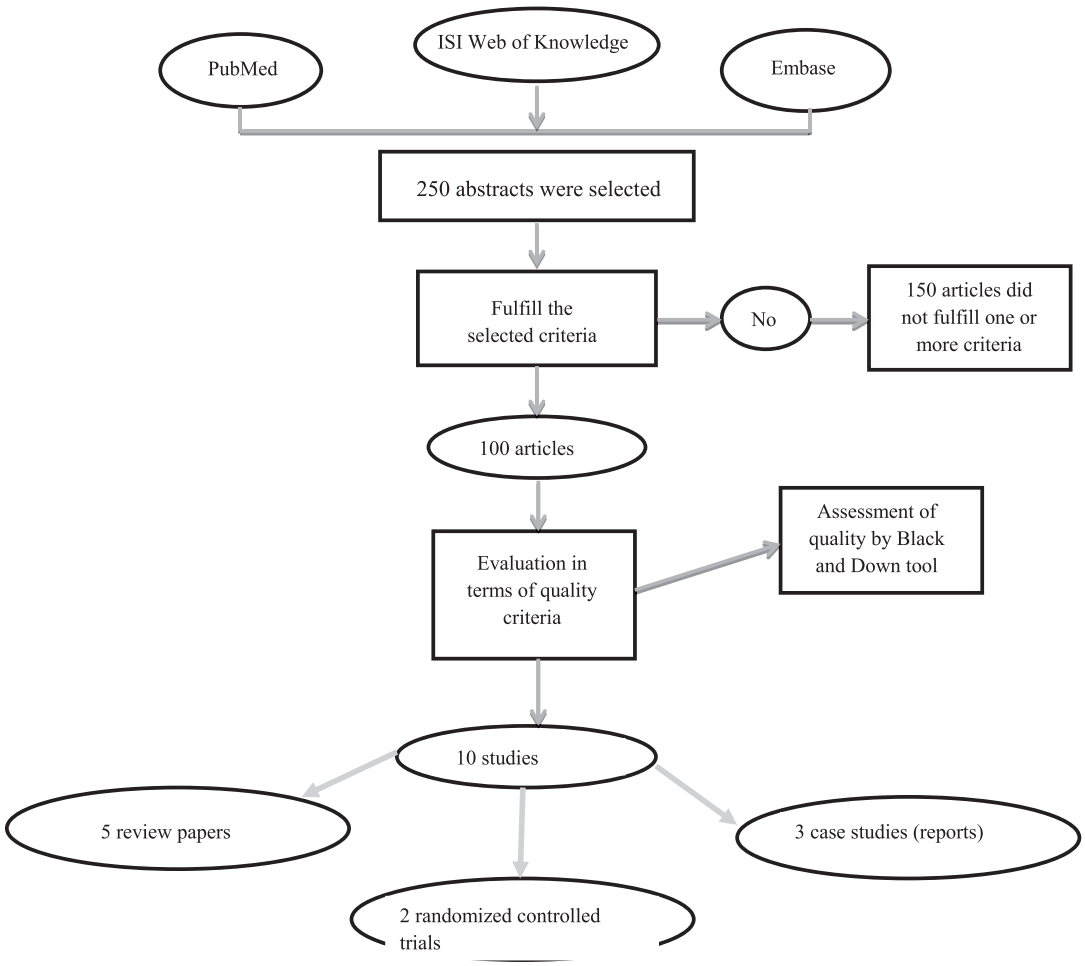

Fig. 1. A diagram of the stages used in this review article

orthoses have not been produced and were evaluated only based on modeling stimulation [38,32]. As can be seen from table 1 there are only 2 clinical randomized trials on robotic treadmill body support systems. The new designed orthoses were only tested on some normal subjects. The quality of the research studies on paraplegic subjects varied between 20-27, based on Black and Down tool.

Is there any difference between the outcomes of rehabilitation of SCI subjects walking with robotic device?

It should be mentioned that the trapeutic benefits association with ambulation is improving bone mineral density, improving the performance of digestive and cardiovascular systems and improving bowel and bladder functions [14,10]. Based on Mechatronic theory, the BMD of long bone depends on the loads applied on the bone produced by ground reaction force and muscular activities [39]. The effects of muscular force on bone density are more than that of the vertical force [39-42]. It has been shown that providing progression force on the hip and ankle joints reduces the EMG activity of the hip joint muscles (by 75% in normal subjects) [37]. Furthermore, it has been emphasized that as pelvic section is surrounded by robotic device, the role of muscles would be decreased. Therefore, it can be concluded that sine the EMG activities decreases follow the use of robotic system, the influence of walking on BMD would be decreased simultaneously. Appropriate neuromuscular activity during practice of voluntary stepping is important for maximizing activity – dependent plasticity of spinal and supra spinal locomotor circuity following SCI [43]. Therefore, the use of robotic assisted walking should be minimized. In contrast to robotic rehabilitation, there are some evidences regarding the positive influence of walking with mechanical de-

vice on BMD, as most part of the loads applied on the limb during walking of paraplegic subjects with the mechanical devices [44,45].

What are the benefits and drawback of robotic therapy technology for SCI?

There are not any specific studies in the literature regarding the benefits and drawback of robotic therapy rehabilitation. However it has been shown that passive guideline and pelvic rotation are the two main issues of this system. Furthermore, it is not possible to select various level of power produced by the system based on the patients need. In other side robotic rehabilitation devices can increase the time of rehabilitation by reducing the number of required therapist.

Is there any difference between the performances of paraplegic subjects while walking with robotic device?

The final version of a robotic portable system designed for paraplegic subjects was Mina orthosis developed by Neuhaus et al. [26]. There is not enough information regarding the performance of subjects with this orthosis. However, it has been reported that walking speed of paraplegic subjects with this orthosis varied between 10-12 m/min, which is not comparable with available mechanical orthoses [26]. The walking speed of the subjects with hip guidance orthosis, which is the best available orthosis for paraplegic subjects varies between 18.2-25 m/min [46, 47,22,48,15], which is significantly more than that with the well-developed robotic systems.

CONCLUSIONS

1. Although various types of orthotic systems have been developed for paraplegic subjects for walking and rehabilitation, there is not enough research in this regard.
2. It is not easy to determine the therapeutic influence of robotic orthosis on the health status of paraplegic subjects.
3. There is a huge gap for a randomized clinical trial research to determine the effect of robotic system on the health status of the SCI subjects.

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