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Static Balance Rehabilitation in Individuals with Incomplete Spinal Cord Injury

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ABSTRACT

Spinal cord injury (SCI) is damage to the tight bundle of cells and nerves that send and receive signals from the brain to and from the rest of the body. SCI can be caused by direct injury to the spinal cord itself or from damage to the tissue and bones that surround it. Patients with SCI often experience motor, sensory and/or respiratory dysfunction, as well as bladder, bowel and/or sexual dysfunction. An incomplete injury means that the spinal cord is still able to transmit certain messages to and from the brain to the rest of the body. Balance dysfunctions are one of the most prevalent impairments post incomplete SCI (iSCI). Static balance is also one of the major determinants of walking function; therefore, discovering effective strategies to improve static balance in this population is significant.

The purpose of this review is to highlight the importance of static balance rehabilitation in individuals with iSCI, as well as to describe effective modes of balance training in this population.

Key Words: static balance, balance impairment, balance training, rehabilitation, incomplete spinal cord injury

Introduction

SCI is a complex condition that disrupts a person's life. According to the World Health Organization (WHO), SCI is defined as damage to the spinal cord, including the conus medullaris and the cauda equina, which causes temporary or permanent changes in its function. Estimated annual global incidence, although there is no reliable estimate of global prevalence, is 40 to 80 cases per million population. Up to 90% of these cases are due to traumatic causes, though the proportion of non-traumatic SCI appears to be growing [1].

Approximately 60% of individuals with SCI suffer an incomplete lesion [2]. Individuals with iSCI often develop impairments in muscle strength, sensation,

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and abnormal muscle tone, making it challenging for them to recover balance function [3]. Among those with iSCI, about 75% will experience at least one fall each year, while standing and walking [4]. Falls can cause fractures, soft tissue injuries, fear of falling, subsequent restriction of activities and community participation. Balance dysfunction is one of the major factors leading to impaired mobility and postural control, affects walking ability and influences balance control in daily life [5,6].

Good balance requires the coordination of muscles and nervous system. The afferent sensory information received through the proprioceptive, visual, and vestibular systems is an important factor for balance control [7-9]. Impairment in one system can lead to higher reliance on the other systems. However, static balance training is often ignored during rehabilitation of patients with iSCI. Therefore, including effective physiotherapeutic strategies to improve static balance in rehabilitation program of individuals with iSCI is important.

PubMed, BioMed central and Cochrane library databases were searched for studies published between 2002 and 2022 using keywords such as, “balance training” and “incomplete spinal cord injury”. Our literature research was completed in June 2022 and the review was carried out according to the guidelines of the PRISMA (12).

Eligibility criteria: Studies providing information on outcome measures and prognostic factors about recovery from balance impairment after iSCI. The articles had to be either written or translated into English. Access to full text was essential.

Study exclusion criteria:Articles that were not written or translated in English were excluded. Articles that were impossible to be accessed in full text were excluded as well. Articles that were case studies were also excluded.

Each record that met the inclusion criteria was fully read and 44 reports were retrieved by the reviewer (Figure 1).

Discussion

The initial electronic database search resulted in a total of 66 articles, of these, 44 were considered for inclusion in this review (Figure 1).

The rehabilitation of patients with SCI is multidisciplinary and comprises multiple aspects [10]. A detailed clinical assessment is significant to set adequate rehabilitation goals. All therapeutic interventions should be monitored with adequate outcome measures [11]. In this section, effective physiotherapeutic approaches of balance training are describedthat aim to modifybalanceand the risk for falls by means of therapeutic exercises, assistive devices like robots or functional electric stimulation, and environmental adaptations in individuals with iSCI.

Strength Training: Observational studies investigating balance issues report that the rehabilitation program should focus on increasing muscle strength of the trunk and lower extremities. For this reason, a physical performance test must be conducted in order to determine the adequate dosage [12].

Locomotor Training: Locomotor training is an activity-based therapeutic intervention whose goal is to activate the neuromuscular system below the level of the lesion to promote recovery of motor function with the purpose of retraining the nervous system to recover a specific task. Activation of the neuromuscular system occurs during repetitive and progressive practice of the desired task; “activity-dependent plasticity” promotes functional reorganization of the neuromuscular system [13,14].

Results of the study of Harkema et al. in 2012 showed that significant functional recovery can occur months to years after iSCI with rehabilitation that involves intensive activity-based therapy. Significant improvements in balancewere observed when locomotor training was delivered as a standardized therapy to individuals with clinically iSCI across seven rehabilitation centers. Patients with AIS grades C and D significantly improved in overall Berg Balance Scale (BBS) scores, indicating better functional ability during sitting or standing. These improvements in overall BBS scores likely responded to the intense retraining of standing and stepping, as well as integration of the practice of sitting and transitional movements in their daily lives [15].

In addition to this, Lotter et al., in 2020, observed gains in balance confidence following task-specific vs impairment-based training, although incidence of falls was also increased with the former protocol. This study delineates the effects of specificity of rehabilitation interventions on locomotor function in patients with motor iSCI, revealing greater walking improvements and balance confidence following stepping versus impairment-based practice [16].

Overground Locomotor Training (OLT): In 2019, Neville et al. demonstrated improvements in balance and gait using a task-specific, performance-based OLT for chronic iSCI. Interventions included two 90-minute OLT sessions per week over 12 to 15 weeks. OLT sessions were built on three principles of motor learning: practice variability, task specificity, and progressive overload. Training used only voluntary movements without any form of support or facilitation. Subjects used only ambulatory assistive devices as required [17].

Body Weight-Supported Treadmill Training (BWSTT):BWSTT allows for the repetitive practice of walking or stepping in a controlled environment in which the individual's weight is partially unloaded and sensory input is provided facilitating normal walking parameters. A harness supports patients' body weight and provides more support than a gait aid [18]. Alexeeva et al., in 2011, compared two forms of device-specific training – body-weight-supported (BWS) ambulation on a fixed track (TRK) and BWS ambulation on a treadmill (TM) to comprehensive physical therapy (PT) for improving walking speed, in persons with chronic, motor-iSCI. A significant improvement in balance was seen only for PT and TRK groups. The results demonstrated that persons with chronic, motor-iSCI can improve walking ability following a concentrated period of ambulation therapy, regardless of training method. Improvement in walking speed was associated with improved balance and muscle strength [19].

Intensive Mobility Training (IMT) is a treatment paradigm that merges BWSTT and massed/intensive delivery of therapy into one cohesive rehabilitative approach. In the study of Fritz et al, participants received IMT three hours per day, 3-5 days per week for 10 days, for a total of 30 hours. Each session devoted a third of the time to therapeutic interventions focused on improving balance, a third to locomotor training with body weight support system, and a third to activities designed to improve muscle coordination, strength, and range of motion. IMT resulted in larger effect sizes for balance and mobility than for gait in individuals with chronic iSCI [20].

In 2018, Martinez et al. showed that for patients with chronic iSCI, a multimodal exercise rehabilitation program incorporating balance exercises with skilled upper extremity exercises showed no benefit compared to an active control program of BWSTT [21].

Robot-Assisted Gait Training (RAGT): RAGT is an exoskeletal-type robot (Lokomat®) with a treadmill base. RAGT allows the patient to safely experience physiological gait patterns with body weight support by a harness. At the same time, an end-effector type robot is used in the clinical field. On the one hand, the exoskeletal-type robot links the ankle, knee, and hip joints to the robot. On the other hand, the end-effector robot attaches only the feet to the footplate, and consequently it allows free movement of the knee and hip joints. This "destabilization training" provided can reinforce the neuronal circuit and contribute to postural control and sensory integration. RAGT in patients with iSCI revealed improvements in mobility-related outcomesand lower extremity motor strength compared to conventional physiotherapy [18].

Nam et al. observed significantly greater improvements in balance in the chronic RAGT groups, compared to the no intervention groups, in patients with chronic SCI. However, no trial with acute participants measured recovery of balance. The acute RAGT groups showed significantly greater improvements in gait distance, leg strength and functional level of mobility and independence than the OLTgroups.Thus, RAGT improves mobility-related outcomes to a greater degree than conventional OLT for patients with iSCI, particularly during the acute stage [22].

However, according to the study of Alashram et al., there is insufficient evidence for the effects of the Lokomat on balance in people with iSCI [23]. Piira et al. reported a significant improvement in the BBS scores after Lokomat training compared to the usual care-control group. The sample size was small; hence, the clinical effects cannot be confirmed [24]. The study of Shahin et al. reported improvements in the BBS scores after RAGT and conventional physical therapy (CPT) experimental and the CPT control interventions, with no significant differences between groups [25]. Labruyere and van Hedel did not show significant differences between groups in the BBS, the Figure Eight Test (FET) and the Falls Efficacy Scale-International Version I (FES-I) scores [26].

In the study of Shin et al., participants received RAGT with Morning Walk® (Curexo, Seoul, South Korea). This is an end-effector type robot which uses a saddle for weight support. All clinical outcomes showed a significant improvement after 20 sessions of RAGT. In addition, they evaluated balance ability as an outcome measure that lacks evidence of the effect of an end-effector RAGT in patients with SCI. The results of this study suggest that the end-effector RAGT could act as task-specific, repetitive, and desensitization training to promote proprioception, balance ability, and walking ability [18].

Moreover, Khan et al., in 2019, conducted research with participants with chronic motor complete or incomplete SCI, who were primarily wheelchair users, and were trained to walk in the powered exoskeleton ReWalk for 12 weeks. In the ReWalk, participants learned sit-to-standtransitionsand vice versa, as well as balancing in standing. Sitting balance was improved in some participants, as seen from the limits of stability and sway speed. About 45 sessions of training are required for individuals with severe SCIin order to achieve walking proficiency in the ReWalk. The ReWalk is a promising device to train walking in individuals with severe SCI with good upper extremity strength [27].

Furthermore, in 2020, Calabro et al., proved the efficacy of robot aided ankle rehabilitation, using the platform robot Hunova, in improving gait performance and balance in persons with iSCIby retraining muscle activation and corticomuscular coherence in a framework of preserved motor coordination. The platform robot Hunova allows for functional sensorimotor evaluation and rehabilitation of the ankle, lower limbs, and trunk in both standing and sitting positions [28].

Functional Electrical Stimulation (FES): FES is a subtype of neuromuscular stimulationin which the stimulation assists functional and purposeful movements. This is accomplished by applying electrical stimulation to muscles that, when they contract, produce a movement that can be used functionally. The order in which the muscles contract, as well as the muscles themselves, are specifically selected to produce the desired movement. A FES system that facilitates a specific movement is often referred to as a neuroprosthesis or motor neuroprosthesis [29].

The ability to stand is often affected by SCI. FES can be used to activate the muscles around the ankle joints which, in combination with a support system for the trunk (e.g., a standing frame or a full-body orthosis), can restore the ability to stand. Additionally, stimulation channels can be used to facilitate trunk control. The Case Western Reserve University/Department of Veteran Affairs (CWRU-VA) neuroprosthesis for standing used a 16-channel implanted stimulator. Bilateral activation of the thighs, hip, and trunk allowed a person with paraplegia to stand upright for eight min, when combined with an ankle–foot orthosis [29].

Audu et al. designed and tested a feedback control system for maintaining seated balance under external perturbations in individuals with thoracic and cervical level SCI. The control system relied on a signal related to the tilt of the trunk from the vertical position derived from a sensor fixed to the sternum to activate user's own trunk and hip extensor muscles via an implanted neuroprosthesis. The results support the feasibility of automatically controlling seated balance with FES. Perturbations up to 45% body weight were successfully rejected by the controller. Consequently, such a controller would be helpful for maintaining trunk balance during everyday activities and prevent falls [30].

Houstonetal.evaluatedatherapeutictoolforstanding balance that combined FES, applied bilaterally to the plantarflexors and dorsiflexors, with visual feedback balance training (FES+VFBT). Visual feedback of the COP location was provided as participants completed the balance exercises and received FES to assist with performance of the exercises. Following training, four of five participants showed improvements on at least one of the clinical balance scales, with less impact on balance confidence as measured by the ABC scale. The area of maximal COP excursion increased for all participants, while there was no significant effect on quiet stance assessments. While most participants did not sustain their improvements at eight weeks post-training, the fact that FES+VFBT was able to elicit improvements in balance ability despite a small training dosage suggests that it is a promising intervention for standing balance rehabilitation among individuals with iSCI [31].

Virtual Reality (VR): VR is a type of interface among user and computer that gains a real-time simulation of activity or environment and allows user interaction via multiple sensory modalities. The VR training activates the cerebral cortex and enhances spatial orientation capacity, hence facilitating the brain cortex to improve the balance ability and improve motor functions. In 2020, Alashram et al. concluded in their systematic review that the influence of VR training on the balance ability in patients with chronic incomplete SCI with C and D on the ASIA scale is promising. In terms of balance, VR training may induce neural plasticity on multiple levels of the central nervous system. They propose that applying 12–20 sessions of 30 to 60 min of VR may show beneficial effects [6].

Besides that, in 2017, An and Park found that semi-immersive VR therapy effectively improves balance and upright mobility function in patients with chronic iSCI. In this study, each subject underwent semi-immersive VR therapy 30 minutes per day, three times a week for six weeks. Semi-immersive VR therapy was provided to stimulate the development of diverse trunk control, multiple directional weight-shifting, agility, and upper-extremity movements in the standing position. Real-time repetitive training through an unpredictable scenario in a virtual environment is considered an effective intervention technique to improve postural adjustment control [32].

Wall et al.in 2015 assessed the effects of virtual reality using the Nintendo™ Wii Fit on balance, gait, and quality of life in ambulatory individuals with iSCI. After playing the Nintendo™ Wii Fit games, subjects demonstrated improved forward and lateral functional reach. At the four-week follow up, subjects were able to maintain the significant changes seen in both outcome measurements. All the Nintendo™ Wii Fit games challenged upright postural stability by requiring the subject to weight shift repetitively in all directions [33].

Additionally, Waliaet al. studied the effectiveness of electrical stimulation-augmented virtual reality training in improving balance in individuals with iSCI. The intervention was delivered as 60-minute sessions, thrice a week for four weeks. Intervention included three phases with kinesiotherapy for 15 min, combination of virtual reality-based balance training and electrical stimulation for 30 min and real-world exercises including movements based on those practiced while engaging in virtual reality tasks for 15 min. This is a protocol which has been designed specifically for iSCI and it is believed that it will result in substantial improvement in standing balance in individuals with iSCI [34].

In the research of Villiger et al., 12 chronic iSCI subjects used a home-based, mobile version of a lower limb VR training system. Movement sensors controlled virtual representations of the legs and feet. The subjects performed home-based training over four weeks, with 16–20 sessions of 30–45 min each. The researchers concluded by ending their study that unsupervised exercises at home with the VR training system led to beneficial functional training effects in subjects with chronic iSCI, suggesting that it may be useful as a neurorehabilitation tool [35].

Visual Feedback: Sayenko et al. showed that individuals with chronic iSCI show improvements in upright static and dynamic postural control after balance training with visual feedback during standing. Participants with chronic motor and sensory iSCI who were able to stand for at least five minutes without any form of assistive device performed the balance training with visual feedback, three days per week, for a total of 12 sessions. They stood on a force platform and were instructed to shift their center of pressure in the indicated directions as represented by a cursor on a monitor [36].

In addition, Tamburella et al. found that visual biofeedback task-specific balance training (vBFB) is effective in improving balance and gait in chronic SCI subjects. Inclusion of vBFB in rehabilitation protocols for chronic SCI subjects effects greater improvements in gait than conventional rehabilitation alone [37].

Reactive Stepping Ability: Reactive balance control describes the ability to recuperate balance after an unexpected balance perturbation and can involve keeping the feet in place or taking one or more steps to increase the size of the base of support. This last strategy is referred to as reactive stepping, which, if compromised, can increase fall risk [38].

Chan et al.in 2020 found that reactive stepping ability of individuals with iSCI (AIS D) is impaired; however, this impairment is not explained by temporal parameters. The findings suggest that reactive stepping should be targeted in the rehabilitation of ambulatory individuals with iSCI [39].

On the other hand, Unger et al, concluded that balance training is beneficial for individuals with iSCI (AIS D), but the addition of manual perturbations (PBT) did not prove advantageous for performance on a measure of reactive stepping ability [40].

Provision of Specific Physical Inputs: In et al. provided evidence that the use of whole-body vibration (WBV) holds promise as a safe and effective intervention to decrease spasticity and improve balance and walking function in individuals with iSCI at the cervical level. The WBV group received 16 minutes of WBV training, twice a day, five days a week for eight weeks. WBV training included four sets of 45 seconds of stimulation and a minute break between each session. Finally, a total of 80 training sessions were provided to each patient. All subjects who performed WBV training had decreased spasticity of the ankle plantar flexors and showed improved balance and walking ability [41].

In 2017, Arora et al. investigated the effect of haptic input via light touch on standing balance of individuals with incomplete iSCI. The results of this study showed that individuals with iSCI improved their standing balance with light touch similar to able-bodied individuals. Without vision, postural sway was reduced to a greater extent in individuals with more intact upper extremities (UE) cutaneous pressure sensation and more impaired lower extremities (LE) proprioception. In addition, individuals with iSCI seemed to rely more on vision for standing balance than able-bodied individuals, confirming previous work [6]. Individuals with and without intact UE sensation responded differently to light touch suggesting that thelevel/extent of injury must be considered. These findings suggest light touch has promise as an intervention for balance impairments in individuals with iSCI, and further research is warranted [9].

Arm Crank Ergometer (ACE) "Spin" Training: In the study of Williams et al., participants completed five weeks of a group ACE "spin" training protocol which featured alterations in resistance and cadence as well as back-supported and unsupported bouts. Participants showed significant improvements in seated balance only when they attempted to sit as still as possible with eyes closed while no effects were seen in static seated balance with eyes open or dynamic seated balance. Static seated balance with eyes closed is a more challenging static balance task than eyes open, and so improvements in this particular condition may indicate the benefits of ACE training. Unsupported ACE was effective in eliciting trunk muscle activity in all participants regardless of injury level. After five weeks of training, participants demonstrated improved static seated balance control with eyes closed. These results indicate that an ACE program with bouts of unsupported cranking may be a beneficial technique to enhance activation of the trunk muscles and improve seated balance control in this population [42].

Aquatic Training: Underwater treadmill training (UTT) is a self-initiated walking intervention which has remained largely unexamined as a means of improving ambulation in individuals with iSCI. Use of water as an unloading medium reduces body weight, thus decreasing strength levels needed to move the lower extremities during self-initiated gait. Other contingent benefits of walking on an underwater treadmill comprise improved balance, increased muscle strength caused by overcoming water resistance and turbulence, generation of muscle activity and gait patterns like those seen in overground walking and enhanced venous return and cardiac preload associated with the effects of hydrostatic pressure in an aquatic environment. Data from the study of Stevens et al. revealed that 8 weeks of UTT improved leg strength, balance, and walking performance in adults with iSCI [43].

Furthermore, Marinho-Buzelli et al. assessed the influence of the aquatic environment on quasi-static posture by measuring COP sway and trunk acceleration parameters after iSCI in water and on land. The results showed that increased COP sway seemed

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to reflect the balance and sensorimotor impairments of the participants, especially when standing with eyes closed in water. Most participants reported that water felt like a safer environment in which to stand [44].

Conclusion

The ability to maintain postural stability and balance during static or dynamic (non-walking) tasks is a major impairment following iSCI and is strongly associated with fall risk and reduced participation. Indeed, impaired balance is a primary predictor of locomotor function in the chronic phases following iSCI and training activities directed toward improving postural control are a major focus of traditional rehabilitation strategies. However, discussions have moved away from training compensatory strategies with limited chances of recovery to acknowledgement that specific rehabilitation strategies may be critically important to enhance balance function. Specific interventions have been designed to challenge trunk stability during sitting exercises and progression to standing balance activities, focusing on symmetrical weight bearing using different weight-shifting techniques. Additional sensory inputs may be provided, including altered visual input to increased visual feedback via virtual reality, or provision of specific physical inputs such as vibratory stimuli and haptic input.

To conclude with, the current review was designed to highlight these strategies as determined by pertinent research studies developed during these past decades. The main positive effect of the balance training on postural control in individuals with iSCIshould be associated with the improvement of existing and the development of new motor strategies, sensorimotor integration, and a direct effect of the training on the muscles' functional properties. Further studies are required to verify the results of selected positive studies incorporating circuit and combined training interventions during static balance training in patients with iSCI, including potential comparative efficacy studies utilizing different therapeutic approaches, and further details on amounts, type, frequency, and intensity of practice provided, to ensure patient's effort and volitional engagement. A

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