# Balance

There are a number of articles that assess balance in participants using exoskeletons. The majority of these articles looked at a population with spinal cord injury (SCI) (28 articles) or stroke (CVA) (18 articles). These publications are a majority case series (26 articles), controlled trials (16 articles), and review articles (15 articles). Most articles assessed balance using the Timed Up and Go test (TUG) (41 articles) and/or Berg Balance Scale (Berg) (18 articles). Review articles examined studies utilizing many exoskeleton devices. Most other studies utilized the Ekso1.1/GT/NR device, referred to as “Ekso” in this paper (36 articles).

*Stroke (CVA)*

There are a number of randomized controlled trials that assess balance changes as a result of using an exoskeleton in the CVA population. Some show that exoskeletons are superior to conventional training in terms of improving balance1–3, while others show equal results between groups4–6. One study that showed that exoskeleton training was superior to conventional gait training was a trial that randomized 40 subjects with strokes occurring at least 6 months ago who received walking therapy conventionally or with Ekso five times a week for eight weeks. The robotic group showed greater changes in TUG than the group receiving conventional gait training.1 When data from this study was analyzed a different way, all Ekso participants achieved the Minimal Clinically Important Difference (MCID) and the Minimal Detectable Change (MDC) for the TUG, while the conventionally trained group only met the MDC.2 A slightly lower dose of therapy 3 times a week over 8 weeks of either Ekso or conventional training resulted in statistically significant improvement in TUG time for both groups, with slight superiority of Ekso.3 On the contrary, another study randomized 44 subjects with ischemic stroke that occurred in the last 4-12 months into receiving daily rehabilitation plus either Ekso or conventional gait training. The dosage provided for both groups was 105 minutes per day, of which 45 minutes were either Ekso or conventional gait training five days per week for four weeks. Balance was measured using a baroresistive platform and it was determined that both groups significantly improved their balance, but neither group outperformed the other in the magnitude of this improvement.4 Another study that showed similar results between the exoskeleton and control groups utilized 17 subjects with subacute stroke and randomized them to receive 12 sessions of either ExoAtlet or conventional gait training. Berg improved significantly in both groups, while the TUG only improved in the ExoAtlet group, though the between group comparison of the change in each measure was not statistically different for either outcome measure.5 One study that was completed in the context of inpatient rehabilitation showed significant improvements in Berg scores, but no between group differences.6

While they didn’t have a control group, other studies compared pre-exoskeleton outcomes to outcomes completed post-exoskeleton intervention. One such study enrolled 19 subjects with chronic stroke and had them walk in Ekso 3 times per week over 4 weeks in addition to 100 minutes per weekday of verticalization. This intervention did result in improvement of -10.32±14.59 seconds in the TUG.7 Another study that showed improvement in TUG after using Ekso in a group of 46 subjects post stroke demonstrated both a greater number of people who could complete the TUG test post intervention and an improvement in test time.8 These subjects ambulated in Ekso a total of 12-20 sessions offered 3 to 5 times per week. Fifteen subjects were unable to complete the TUG at baseline and regained the ability to complete the test post-intervention.8 For the 7 participants who could complete the test at both time points, their time improved from 38.71 to 30.00 seconds.8 A third study showing positive improvements in the TUG had 14 participants in a rehabilitation setting receiving both standard of care and Ekso therapy during their length of stay. At baseline, all subjects took greater than 30 seconds to complete the TUG and by the end of the study, 12 of the 14 improved their TUG time significantly.9 A smaller study showed similar improvements in TUG in 2 individuals with acute stroke who ambulated in Ekso 3 times per week over 10 weeks. One subject improved TUG from 10 to 7.82 seconds, and the other improved from 11.46 to 9.45 seconds.10 A different study of 14 individuals had subjects participate in an intensive program of technology assisted training which included multiple devices. Berg scores improved from 32 to 39, which was statistically significant after 28 to 82 sessions of technology assisted training.11 While all pre-post studies discussed above showed positive results of an exoskeleton-based intervention on balance, one study did not show significant changes in TUG time in 5 subjects after 15 sessions of Ekso.12

There are seven known review articles that comment on exoskeletons and their effect on balance in persons with stroke. Three of them examined randomized controlled trials and showed that exoskeletons were superior to control groups providing conventional therapy for improving balance.13–15 Another review, however, reported that exoskeleton walking demonstrated no further improvement on balance than conventional therapy.16 Another review attempted to determine the best combination of treatment methods to improve balance measured by Berg and found that a combination of robotic training, body weight supported training, and conventional physical therapy was best.17 A final review also looked at combinations of treatments including those that are robot assisted and virtual reality based. It found that a combination of these is best for improving Berg (82%) and TUG (93.3%).18

*Spinal Cord Injury (SCI)*

While none use balance measures as primary outcomes, there are a few studies that use subjects with SCI and assess changes in balance as compared to another intervention. Most compared Ekso training to conventional gait training. One study of 7 participants with chronic motor incomplete SCI randomized them to receive their selected gait training five times a week for 3 weeks. Both groups improved in TUG time, with the exoskeleton group having a greater percent change, but the control group having a statistically significant change.19 It is important to note that in this study, the two groups were different at baseline, which may have skewed the results.19 Another study that compared Ekso, conventional training, and body weight supported treadmill training found no statistically significant difference in improvement of TUG time, which improved by 18.7%, 12.7%, and 19.9% respectively.20 One study utilized Functional Electrical Stimulation (FES) in conjunction with Ekso walking and found that balance measured by Berg improved more during the intervention period than control period in a crossover study of 6 persons with acute SCI.21

Single group studies examined changes in balance outcomes completed before and after exoskeleton intervention. A unique study of 8 participants with chronic motor complete SCI who averaged 30 sessions walking in the ReWalk compared the seated balance of these participants with 7 able-bodied controls using computerized posturography. The majority of participants had improvement in their seated balance after exoskeleton intervention with significant increases in ability to move center of pressure further in all directions.22 A similar study showed improvement in limits of stability in sitting as well as improvements in sway speed in sitting with eyes closed.23 Other studies showed improvements from pre- to post-exoskeleton intervention in the Berg and the TUG in a number of exoskeletons including ExoAtlet, Ekso, Indego, and Able and with different durations of interventions ranging from a total of 12-24 sessions.24–28

A number of studies examined TUG completed in an exoskeleton.28–38 Some of these studies had the purpose of testing controls of the exoskeleton, and therefore the TUG was chosen as it involved the user transitioning from sit to stand, walking, and returning to sit. Another study modified the Berg to assess it in an exoskeleton, understanding that certain items including standing on one leg, tandem stance, and picking up an item from the ground are not possible in an exoskeleton.39 For studies that completed testing in an exoskeleton over multiple time periods, improvements in balance were seen overtime.35,36,38,39 A combination treatment of 20 sessions each of Ekso walking and FES cycling produced statistically significant improvements in TUG.33

A number of reviews using subjects with SCI comment on balance recovery after using an exoskeleton, but only one known article has this outcome as a primary goal of completing the review. In this article, 19 papers were selected. Eleven of 13 studies that examined functional restoration reported statistically significant improvements or improvements greater than MCID for gait and balance measures.40 A metanalysis which looked at a variety of outcome measures showed that persons with SCI who received wearable exoskeleton gait training improved TUG times based on 5 studies with 93 participants.41 Another meta-analysis showed similar results with the Berg, showing that exoskeleton training was more effective in improving balance compared to conventional gait training.42 A final review aimed to compare the effects of exoskeleton training on persons with different SCI levels and severity. In persons with incomplete SCI who received 20 sessions, TUG improved, while no improvement was seen in those trained in a body weight supported treadmill based robotic device.43

*Multiple Sclerosis (MS)*

There are a number of studies and one review all examining the effect that walking in an exoskeleton has on balance in persons with MS. Most assess balance using the TUG. One randomized controlled trial compared 4 weeks of Ekso walking with 4 weeks of conventional therapy delivered twice weekly. While not statistically significant, the robotic group demonstrated substantial improvements (from 19.3 seconds to 14.3 seconds) while the conventional therapy group demonstrated minimal worsening (from 22.4 seconds to 22.8 seconds).44 Another randomized trial utilized 36 participants who required an assistive device for outdoor walking and all received weekly, 1 hour conventional PT sessions. In addition, the intervention group also received twice weekly Ekso sessions for a duration of 3 months. The group that received Ekso training improved on their TUG time from 22.86±12.04 to 20.61±10.37 seconds, while the control group worsened by an average of 1.35 seconds.45 It was also important to note that this improvement did not increase fatigue perception, which is important in persons with this diagnosis.45 A smaller study randomized a group of 4 equally to either receive 8 sessions of Ekso or conventional gait training. The group who walked in Ekso improved by 26% while the control group only improved by 1% on the TUG.46 In a retrospective study, 20 patients were divided into two groups, one who received gait training with Ekso and the other through conventional methods for a total of 40 sessions. Both groups improved significantly on the Berg, but only the Ekso group demonstrated a significant improvement in TUG.47

In a unique study that used force plates to determine postural balance and center of pressure displacements, 14 subjects walked in Ekso 15 times over 3 weeks. By this method of measurement, no significant difference were seen between assessment time periods.48

One study demonstrated no significant improvement in balance due to walking in an exoskeleton. This case series had 10 subjects walking in Ekso for 15 sessions over 3 weeks. While improvement from 33.4±12.2 to 28.6±13.7 seconds was seen, this improvement was only approaching significance with a p value of 0.1.49 This study only recruited subjects with an EDSS from 5 – 6.5 (ambulates without aid or rest for 200m to constant bilateral UE assist walking for 20m without rest), whereas a case study of one woman with an EDSS of 8 (restricted to bed or chair) also showed no improvement in balance measured by the Berg after 15 sessions of Ekso walking provided twice per week.50 Her score was a 4 at both baseline and conclusion of the study.50 These EDSS scores do not differ significantly from participants recruited in studies above where significant improvements in balance could be seen.

One review focusing on participants with MS who used wearable or grounded exoskeletons showed that intervention groups exhibited significant improvement in balance when it was measured as a secondary outcome.51

*Acquired Brain Injury*

Only one article exists that looks at balance in a person with a brain injury. This case study examined a 22 year old male who was 2 years post traumatic injury. He walked in Ekso three times a week for four weeks. While the primary purpose of this article was to measure cortical activation, clinical measures including the TUG were completed and an improvement from 17.97 seconds to 14.69 seconds was seen.52

*Review Articles*

One article examined use of a variety of devices including exoskeletons on aging adults who were 65 and above and found that use of these devices, particularly with persons who have a neurological diagnosis, can improve balance as measured by Berg and TUG.53

*Conclusion*

While there is heterogeneity in this research in terms of device used, frequency and duration of intervention, subject diagnosis, and outcome assessing balance, most of the literature suggests that using an exoskeleton can improve balance in adults with neurological conditions. When tested in the exoskeleton, the literature agrees that with further practice in the device, balance outcomes improve. Limitations of the literature on this topic include that balance is not frequently a primary outcome measure, and that TUG is sometimes used as a measure of function versus balance. Like other research on exoskeletons, there is extreme variety in dosage and what is completed in a research setting is likely not transferable to a clinical setting.

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ABI = acquired brain injury, CVA = stroke, MS = multiple sclerosis, SCI = spinal cord injury