Lokomat Robotic-Assisted Gait Training Improves Balance and Muscle Strength in Neurological Patients with Oncological Complications: A Retrospective Study

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Abstract

Background: Central nervous system (CNS) malignancies often result in significant physical and cognitive impairments, including gait and balance dysfunction. Robotic-assisted gait training, particularly using the Lokomat device, has emerged as a promising neurorehabilitation modality to address these deficits. However, data on its efficacy in patients undergoing oncological treatment remain limited.

Objectives: To evaluate the effectiveness of a 12-week comprehensive Lokomat-based robotic-assisted exoskeleton therapy on muscle strength and balance in patients with CNS malignancies.

Methods: This retrospective study included 12 patients with CNS malignancies who underwent Lokomat therapy at Sultan Qaboos Comprehensive Cancer Care and Research Centre (SQCCCRC) between April 2022 and December 2024. Isometric muscle force (L-Forces) of hip and knee joints and the Berg Balance Scale (BBS) were assessed pre- and post-treatment, and changes were examined using the Wilcoxon signed-rank tests.

Results: Significant improvements were observed in lower extremity isometric muscle strength: hip flexors (mean difference = +13.8 Nm, $p = 0.0001$), hip extensors (+14.4 Nm, $p = 0.0079$), knee flexors (+8.4 Nm, $p = 0.0011$), and knee extensors (+2.9 Nm, $p = 0.0017$). BBS scores improved significantly from 20.5 to 34.8 ($p = 0.0025$), indicating enhanced balance. No adverse events were reported.

Conclusions: Lokomat-based robotic-assisted gait training significantly improved muscle strength and balance in patients with CNS malignancies undergoing oncological treatment. These findings support the integration of robotic neurorehabilitation into multidisciplinary cancer care, though further research with larger cohorts and longer follow-up is recommended.

Keywords: Central nervous system (CNS) malignancies, Brain and spinal tumours; Lokomat therapy; balance; muscle activity.

Introduction

Central nervous system (CNS) malignancies, including brain and spinal tumours, are associated with substantial morbidity and mortality due to the neurological impairments they cause.[1–3] These tumours, whether primary or metastatic, disrupt normal neural function and frequently result in significant physical and cognitive deficits.[2,,4,5] Although survival rates for high-grade brain tumours such as glioblastoma multiforme (GBM) have modestly improved with advances in surgery, chemotherapy, and radiotherapy,[6,7] many patients continue to experience persistent functional limitations that negatively affect quality of life.

Globally, primary brain tumours occur at an incidence of approximately 25.48 per 100,000 person-years, with meningiomas representing the most common benign type and glioblastomas the most frequent malignant form.[8-10] In Oman, astrocytic tumours account for the majority of CNS tumours, followed by medulloblastomas[11]. Spinal cord tumours are less common; however, the spine is a major site for metastasis, and metastatic spinal cord compression remains a serious complication in oncology patients.[11] Despite these epidemiological insights, functional outcomes and rehabilitation needs in this population remain insufficiently addressed.

Neurological deficits in patients with CNS tumours arise from both disease progression and treatment-related effects. Tumour characteristics such as size, location, and grade, along with surgery, chemotherapy, and radiation therapy, can lead to motor weakness, impaired coordination, peripheral neuropathy, aphasia, visual field deficits, seizures, and cognitive dysfunction.[12] These impairments often persist beyond acute treatment and significantly limit independence in activities of daily living (ADLs).

Rehabilitation therefore plays a critical role in improving functional outcomes and survivorship in neuro-oncology patients. Multidisciplinary, individualized neurorehabilitation programs, including aerobic and resistance exercises, neuromuscular training, and task-specific interventions, have demonstrated benefits in muscle strength, endurance, balance, gait, and overall functional capacity.[13,14] Evidence suggests that targeted rehabilitation in brain and spinal tumour patients can yield functional gains comparable to those observed in other neurological populations, such as stroke survivors[13]. However, access to structured and standardized neurorehabilitation programs for oncology patients remains inconsistent, and clear clinical protocols are lacking.[13]

In recent years, robotic-assisted gait training (RAGT) has emerged as a promising intervention for individuals with significant gait impairments.[15-18] Compared with conventional physiotherapy, RAGT provides high-intensity, repetitive, and task-specific training while reducing physical strain on therapists. Robotic devices are broadly classified into end-effector systems and exoskeleton-based systems, such as the Lokomat (Hocoma AG, Zurich), which delivers treadmill-based gait training with bodyweight support and guided joint movement.[15,18] Evidence, primarily from stroke populations, indicates that RAGT may improve gait performance and promote neuroplasticity through enhanced cortical activation,[18-21]

Despite growing support for robotic-assisted rehabilitation in neurological disorders, its application in neuro-oncology remains largely underexplored[22,23]. Patients with CNS tumours frequently receive limited rehabilitation during or after oncological treatment, and evidence-based robotic rehabilitation protocols specific to this population are scarce.[24] To our knowledge, this study is among the first to evaluate the effectiveness of Lokomat-based robotic-assisted exoskeleton therapy on balance and muscle strength specifically in neurological patients with oncological complications.

Methods

This study was a retrospective investigation evaluating the effectiveness of Lokomat training (robotic-assisted exoskeleton) on balance and muscle activity in neurological patients with oncological complications.

After obtaining ethical approval from Sultan Qaboos Comprehensive Cancer Care and Research Centre (SQCCCRC), we collected data of 12 patients with CNS malignancies who underwent RTGT using the Lokomat neurorehabilitation program. The study was conducted in the Department of Physical Therapy and Rehabilitation at SQCCCRC between April 2022 and December 2024, with the goal of assessing the effectiveness of robotic neuro-rehabilitation in enhancing balance and muscle activity.

All participants were informed about the purpose and procedure of the study. The study included individuals diagnosed with brain and spinal tumours. Electronic medical records of patients who participated in the Lokomat robotic-assisted exoskeleton neurorehabilitation program during their regularly scheduled physical therapy sessions between April 2022 and December 2024 were reviewed based on the following inclusion criteria: age 16 years or older, medically suitable for gait training, and meeting Lokomat Pro (Hocoma AG, Zurich, Switzerland) specifications (height between 5 and 6 feet 4 inches, weight under 135 kg, upper leg length less than 47 cm, greater than 35 cm).

Participants were excluded if they had any contraindications for lokomat use as established by the manufacturer. These include active heterotopic ossification, severe spasticity, significant contractures, colostomy, pregnancy, impaired skin integrity, hemodynamic instability, unresolved deep vein thrombosis, uncooperative or aggressive behaviour, severe cognitive deficits, mechanical ventilation, and lower limb prosthesis.

Demographic data, including age, gender, body mass index (BMI), and diagnosis, were recorded. Information related to brain and spinal cancer treatments- such as surgical intervention and adjuvant treatments (including radiation therapy and chemotherapy) was obtained through chart review for all patients.

Table 1: Characteristics of the study population.

Variable	**Med [IQR], n/N (%)**
Patients, N=12	
Age (years)	35 [23.8;55.2]
Sex	
Female	3/12 (25%)
Male	9/12 (75%)
Body Mass Index (BMI)	22.2 [20.7;27.2]
Weight (kg)	63.5 [52.5;79.2]
Height (cm)	165. [162.2;168.1]
Number of sessions	9. [6.5;12.2]
Diagnosis	
Astrocytoma	1/12 (8.33%)
Atypical lipomatous tumor	1/12 (8.33%)
Cerebellar brain tumor	1/12 (8.33%)
Breast Cancer + Cerebrovascular accident	2/12 (16.67%)
Glioblastoma	1/12 (8.33%)
Glioblastoma multiforme	1/12 (8.33%)
Medulloblastoma	1/12 (8.33%)
Pineal body germinoma	1/12 (8.33%)
Caecum carcinoma + Right basal ganglia infarct	1/12 (8.33%)
Mets with Spinal cord lesion	1/12 (8.33%)
Thalamic glioma	1/12 (8.33%)
Treatment	

Variable	Med [IQR], n/N (%)
Patients, N=12	
Age (years)	35 [23.8;55.2]
Sex	
Chemotherapy	1/12 (8.33%)
Surgical	4/12 (33.33%)
Surgical & chemotherapy	1/12 (8.33%)
Surgical & radiotherapy	1/12 (8.33%)
Surgical, radiotherapy & chemotherapy	5/12 (41.67%)
Joints, N=15	
Side	
Left	8/15 (53.33%)
Right	7/15 (46.67%)

Electronic medical records of patients with CNS malignancies treated at the Sultan Qaboos Comprehensive Cancer Care and Research Centre between April 2022 and December 2024 were retrospectively reviewed. Patients referred to the neurorehabilitation program and treated with robotic-assisted gait training (Lokomat Pro) were included. Eligibility for Lokomat therapy was determined by certified physiotherapists after assessment of indications, precautions, and contraindications. Lokomat training was delivered by experienced physiotherapists following standardized setup procedures to ensure proper alignment and patient safety (Figure 1). Patients were secured using a harness system with adjustable body-weight support (BWS) and lower limb orthoses. Initial BWS was set at approximately 50% of body weight and was progressively reduced in increments of about 10% per session, as tolerated, without significant knee buckling or toe drag. Each session followed three sequential phases: (1) Safe Walk, ensuring patient safety and gait stability; (2) Physiological Walk, optimizing parameters to approximate a normal gait pattern; and (3) Goal-Oriented Walk, tailoring gait parameters to achieve individualized functional objectives. Treadmill speed ranged from 0.5 to 3 km/h and was adjusted to the maximum level tolerated by each patient. The initial session did not exceed 20 minutes, while subsequent sessions lasted 30–45 minutes depending on tolerance and stage of recovery. Acute patients (≤6 months) received five sessions per week, whereas chronic patients (>6 months) received three sessions per week, with a minimum duration of 30 minutes per session. All session parameters, including speed, BWS, and duration, were documented and progressively adjusted according to patient performance. In addition to robotic training, participants were prescribed a home exercise program consisting of range-of-motion, balance, coordination, and gait exercises, with instructions provided to patients and caregivers.

Figure 1: Lokomat neurorehabilitation training (robotic-assisted exoskeleton**).**

The Lokomat enables objective measurement of patient performance during rehabilitation. In this study, isometric force of the lower extremities (L-Forces) was used as an outcome measure, given the established relationship between lower limb muscle strength and walking ability in individuals with neurological movement disorders (NMD). Previous studies have demonstrated that Lokomat-based measurements of hip and knee flexors and extensors provide reliable assessments of maximal voluntary isometric muscle force, supporting their use for documenting rehabilitation progress.[25] Additionally, the Lokomat has been shown to reliably assess joint position sense in individuals with incomplete spinal cord injury, further supporting its utility as a comprehensive assessment tool in neurological rehabilitation.[26]

Balance was evaluated using the Berg Balance Scale (BBS), a widely used clinical measure of functional balance in adult neurological populations, including patients with brain tumors.[26,27] The BBS assesses balance through standardized functional tasks and provides a quantitative score reflecting balance performance. The scale has demonstrated strong reliability and validity across neurological populations and has been correlated with functional outcomes such as mobility and independence.[248-32]

Sample size were 12 participants enrolled in the study. This sample size ensures sufficient statistical power, i.e., 80%, to detect a large effect size (Cohen's d = 0.7) with a 5% significance level using a paired t-test.

Descriptive statistics analyses were used to examine the frequency distributions and calculate the scores of scales and subscales, and were defined with using either mean, standard deviation (SD), median, and interquartile range (IQR). Categorical variables were presented as frequencies and percentages. The Wilcoxon signed-rank test was used to compare differences in quantitative variables before and after the treatment. Effect sizes were calculated using the Cohen's d method with the effsize package (Torchiano M [2020]. _effsize: Efficient Effect Size Computation) of the R statistical software (R Core Team [2025]. R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria). The relationship between improvement of

functional and neurological recovery (gait) improvement by balance, muscle activity, and functional independence in patients with CNS malignancies was assessed using Spearman's correlation test. All tests of statistical significance are two sided and were considered statistically significant at p-values ≤ 0.05. The R statistical software was used for the analyses.

All data collected in this study were treated, managed, and stored strictly confidentially in Systems, Applications and Products (SAP) software/ program in SQCCCRC. To ensure that no items were missing from the patient-reported outcome questionnaires, the "Required fields" option was activated. Data quality was ensured through answer validity and double data entry when outcome assessors enter the functional performance data in the SAP software/ program. Each participant was labelled with an ID number in the SAP software/ program -database to ensure pseudo-anonymity. Personal data were kept separate from the main data to protect confidentiality throughout each phase of this study. To analyse data, all electronic data were uploaded encrypted to a password-secured server to comply with current data protection standards. The data set will be stored for five years after completing the study, the anonymized dataset will be available upon reasonable request for the corresponding author.

Results

Twelve patients were included in the study, with a total of 15 joints treated. The median age patients were 35 years [IQR: 23.8–55.2], nine (75%) of the patients were male (Table 1). Median weight was 63.5 kg [IQR: 52.5–79.2], height was 165 cm [IQR: 162.2–168.1], and BMI was 22.2 [IQR: 20.7–27.2]. A total of 15 joints were treated.

In the current study, we calculated the differences in isometric force in the lower extremity (L- Forces) for right and left hip and knee flexors and extensors (Figures 2-5). L-Forces of hip and knee joints (flexors and extensors) and BBS showed significant improvements following robotic-assisted exoskeleton (Lokomat) (Table 2). L- forces of hip flexors increased from a mean of 34.5 (SD = 24.1) pre-treatment to 54.8 (SD = 32.1) post-treatment (mean difference = 13.8, SD = 20.9;

p-value = 0.0001, d = 0.66), and hip extensors improved from 18.2 (SD = 22.4) to 36.0 (SD = 32.6) post-treatment (mean difference = 14.4, SD = 25.3; p-value = 0.0079, d = 0.56). L- forces of Knee flexors increased from 19.9 (SD = 20.2) to 32 (SD = 25.2) post-treatment (mean difference = 8.4, SD = 9.2; p-value = 0.0011, d = 0.43), and knee extensors improved from 27.3 (SD = 21.4) to 34.3 (SD = 24.8) post-treatment (mean difference = 2.9, SD = 14.6; p-value = 0.0017, d = 0.31). The BBS was measured in pre- and post-Lokomat therapy for each participant (Figure 6). Overall BBS score significantly improved from a mean of 20.5 (SD = 9.9) pre-treatment to 34.8 (SD = 15.6) post-treatment (mean difference = 14.2, SD = 8.6; p-value = 0.0025, d = 1.09, n = 12 patients).

Given the small sample size (12 patients, 15 joints), results should be interpreted with caution. Although statistically significant improvements were observed, the limited cohort size restricts generalizability. Nevertheless, the magnitude of changes in muscle strength (L- Forces) and BBS scores suggests clinically meaningful improvements in functional performance.

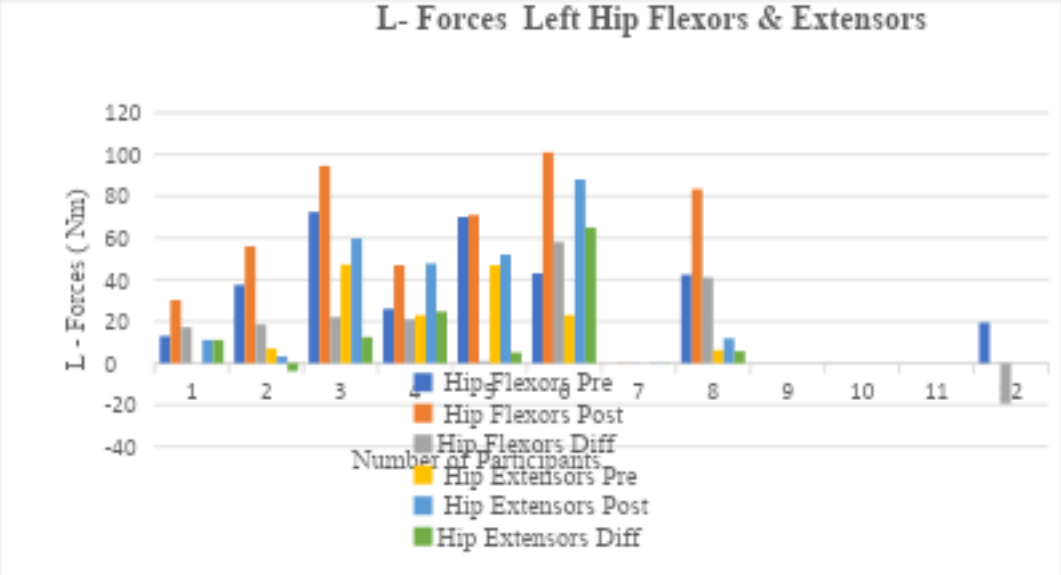

Figure 2: L- Forces of Left Hip Flexors and Extensors.

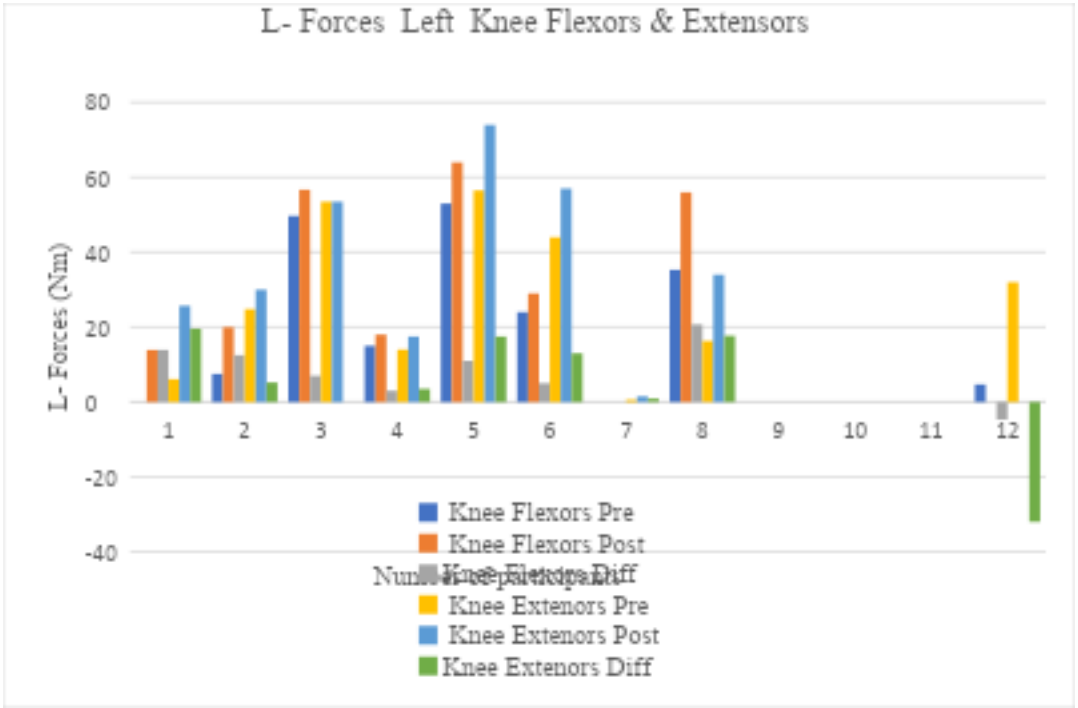

Figure 3: L- Forces of Left Knee Flexors and Extensors.

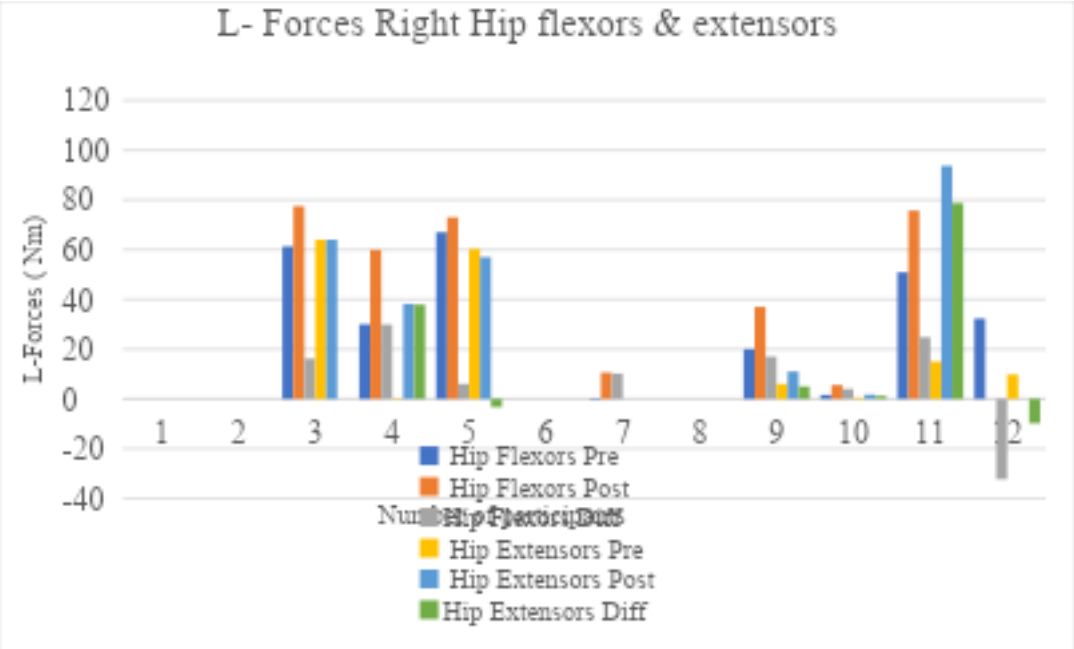

Figure 4: L- forces right hip flexors and extensors.

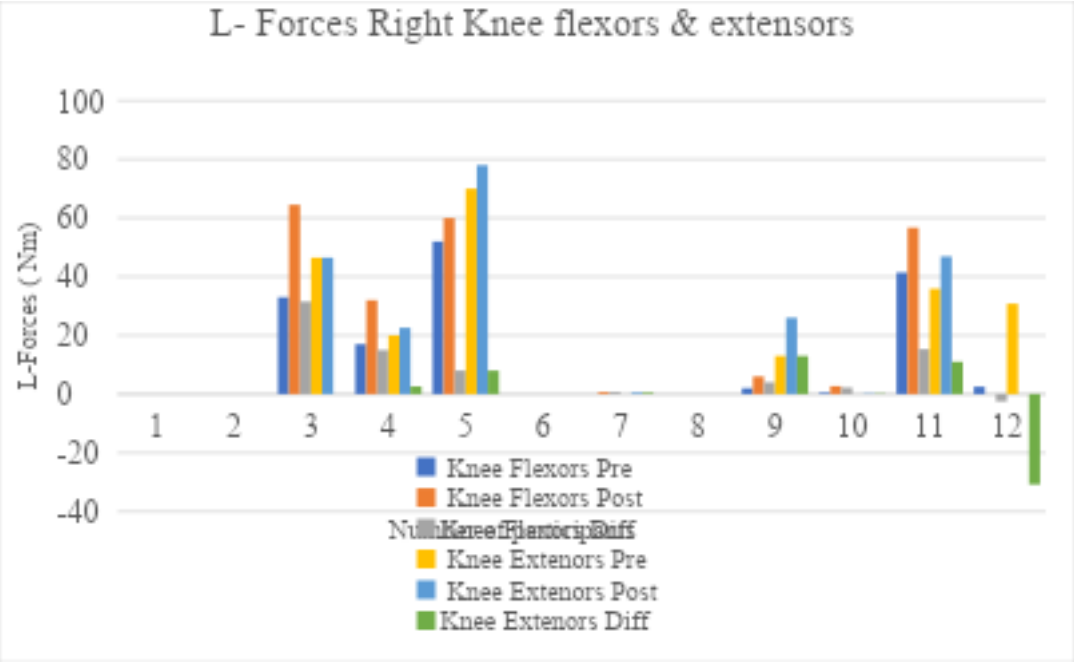

Figure 5: L- Forces of Right Knee Flexors and Extensors.

Table 2: L- Forces and Berg Balance Scale pre- and post-treatment Lokomat measurement.

	N	**Pre-treatment Mean (SD)**	**Post-treatment Mean (SD)**	**Difference Mean (SD)**	**Cohen's d Effect size**	**P-value**
L–Forces (Nm)	15 joints					

Hip flexors		34.5 (24.1)	54.8 (32.1)	13.8 (20.9)	0.66	0.0001
Hip extensors		18.2 (22.4)	36.0 (32.6)	14.4 (25.3)	0.56	0.0079
Knee flexors		19.9 (20.2)	32.0 (25.2)	8.4 (9.2)	0.43	0.0011
Knee extensors		27.3 (21.4)	34.3 (24.8)	2.9 (14.6)	0.31	0.0017
Balance	12 patients					
Berg Balance Scale (BBS)		20.5 (9.9)	34.8 (15.6)	14.2 (8.6)	1.09	0.0025

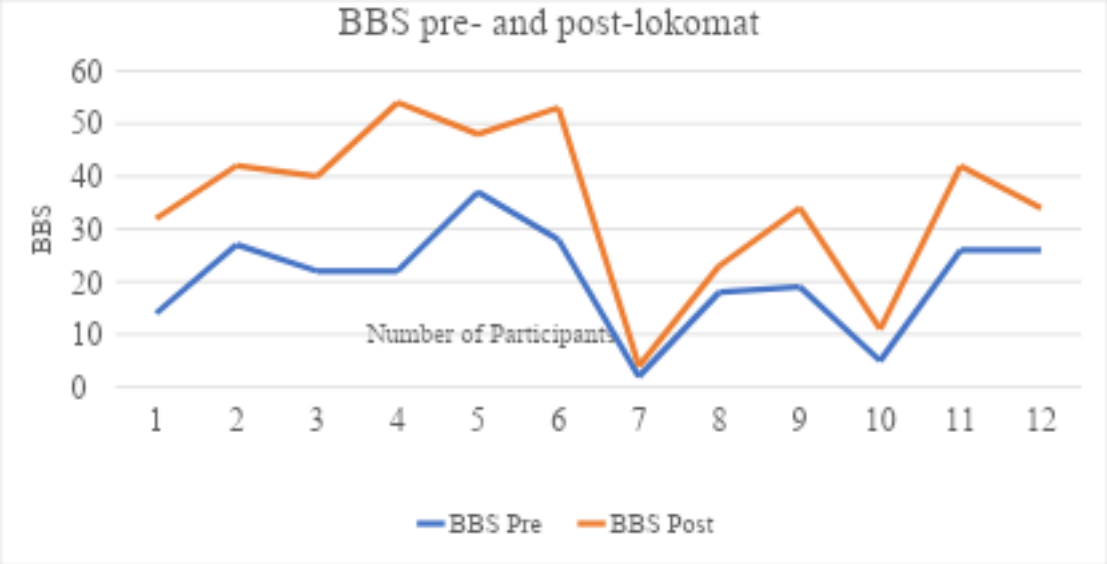

Figure 6: BBS pre- and post-lokomat neurorehabilitation therapy.

Discussion

One of the primary neuro-rehabilitation goals of CNS malignancy patients is to regain motor and sensory skills.[33] Improving gait is particularly significant, as it promotes a patient's autonomy and increases their safety throughout daily activities.[34]

Our investigation into the impact of robotic-assisted exoskeleton therapy using the Lokomat on isometric muscle strength and balance in individuals with lower-extremity impairments yields compelling results. Specifically, significant enhancements were noted across hip and knee flexors and extensors, as well as a marked increase in BBS scores.

In the present study, isometric muscle force in the lower extremities (L-forces) of the hip and knee joints demonstrated significant improvements following robotic-assisted exoskeleton training with the Lokomat. Hip flexor and extensor L-forces showed marked improvement, and similar results were observed in knee flexor and extensor forces. These strength gains are aligned with broader findings showing that robot-assisted training enhances lower-limb muscle activation and strength, including in neurological populations and older adults—though many of those studies focused on metrics such as EMG activity or functional strength gains.[35,36] On the other hand, numerous studies have investigated the comparative effectiveness of Lokomat-assisted therapy versus conventional rehabilitation approaches; however, the consensus remains inconclusive. Multiple studies have reported no significant advantage of Lokomat over standard therapeutic methods.[37-39] Dellan, for instance, argued that existing evidence largely positions Lokomat therapy as equivalent—rather than superior—to traditional interventions,[40] This sentiment is echoed by Bonnyaud, who emphasized that despite the variety of techniques applied to gait

rehabilitation in patients with spastic hemiparesis, no single method, including the Lokomat, has consistently demonstrated clear superiority.[38]

Systematic reviews over recent decades have attempted to synthesize findings from these comparative studies—evaluating Lokomat against conventional therapy, overground walking, or treadmill training. These reviews generally conclude that while Lokomat therapy can be effective, its outcomes are often comparable to those achieved through traditional physical therapy.[40-42] Nonetheless, the evidence is not entirely one-sided. A subset of studies has indicated a potential benefit of the Lokomat over conventional methods,[43,44] though this is counterbalanced by research that found no such advantage and even advised caution in adopting robotic-assisted therapy as a primary modality.[37,45]

Our trial demonstrated a significant improvement in balance, as measured by the BBS. This substantial improvement is consistent with broader trends observed in Lokomat-assisted therapy studies, which often report superior balance outcomes compared to conventional rehabilitation methods. For instance, a systematic review and meta-analysis found that Lokomat training was associated with significantly greater improvements in BBS scores than traditional physiotherapy (mean difference ≈ 2.71; $p < 0.01$).[46]

Despite these encouraging results, there remains a notable gap in research examining the effects of Lokomat therapy on balance in individuals with brain or spinal tumours. To our knowledge, this study is among the first to investigate Lokomat therapy's impact on balance outcomes in this population. Most existing literature has focused on conditions such as stroke, SCI, traumatic brain injury, and cerebral palsy. In stroke rehabilitation, considerable evidence supports the effectiveness of Lokomat-based training. A meta-analysis by Kim et al. (2021) reported that robot-assisted gait training—particularly with exoskeletal devices like the Lokomat—significantly improved BBS scores in stroke patients, with more pronounced improvements seen when total therapy time exceeded 10 hours.[47] Similarly, Wu et al. (2021) found an average BBS improvement of 13.9 points in patients receiving Lokomat-assisted training compared to 9.7 points in those undergoing conventional physiotherapy; however, this between-group difference was not statistically significant.[48] Furthermore, a randomized controlled trial by Choi et al. (2019) involving patients with infratentorial strokes demonstrated comparable BBS improvements when robotic training was combined with standard therapy.[49]

In the SCI population, Lokomat therapy has been linked to enhanced gait distance, leg strength, and walking symmetry. However, balance—as specifically measured by the BBS—has rarely been a primary endpoint in these studies, limiting definitive conclusions about the device's effectiveness in improving balance within this group.[50,51]

In summary, while Lokomat-assisted therapy has demonstrated clear benefits in improving balance among stroke patients, with some evidence supporting its use in SCI populations, its application in neuro-oncology remains largely unexplored. Given the high prevalence of balance impairments among patients with brain and spinal tumours, future research should focus on assessing the feasibility, safety, and effectiveness of robotic-assisted gait training (RAGT) in this group, using objective outcome measures such as the Berg Balance Scale.

From a clinical perspective, Lokomat therapy appears feasible and safe in oncology settings when delivered within a multidisciplinary care model. Its ability to provide intensive, task-specific gait training with minimal physical burden on therapists may be particularly valuable for patients undergoing active cancer treatment. However, considerations such as cost, accessibility, and availability of trained personnel may limit widespread implementation and should be addressed in future health services research.

One limitation of this study was the relatively short duration of patient follow-up. This was influenced by several factors affecting patients' ability to attend robotic neurorehabilitation sessions at the Sultan Qaboos Comprehensive Cancer Care and Research Centre (SQCCCRC), including comorbidities, progression of malignancies (brain and spinal tumours), ongoing treatments, place of residence, and financial limitations. We recommend implementing long-term robotic neurorehabilitation—lasting more than three months—in accordance with the recommendations from the blinded randomized clinical trial by Kelley and colleagues.[52]

Another limitation was the small sample size, due to the dependence on referrals of brain and spinal tumour patients from other healthcare facilities in Oman and the fact that the study was conducted at a single center. Additionally, the study did not assess gait, which is a crucial component of functional independence and safety and

requires significant motor and sensory integration, especially for patients recovering from brain and spinal tumour treatments.

Moreover, the heterogeneity of diagnoses and oncological treatments may have influenced rehabilitation outcomes, limiting the ability to attribute effects to specific tumour types or treatment stages. Therefore, future studies should aim to include a larger sample size, incorporate gait assessments, and extend the follow-up period.

Conclusions

Robotic-assisted gait training using the Lokomat significantly improved lower limb muscle strength and balance in patients with CNS malignancies undergoing oncological treatment. These findings highlight the potential of Lokomat therapy as an effective neurorehabilitation tool in this population. However, larger, multi-centre studies with extended follow-up and comprehensive gait analysis are needed to validate and generalize these results.

Disclosure

No conflicts of interest (All authors declared). No financial support was received for this work

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