Case Report

Reversal of Chronic Post-Stroke Genu Recurvatum with Progressive Robotic Gait Training: A Case Report

Parit Wongphaet and Kittiphon Jitardhan
Department of Rehabilitation Medicine, Samrong General Hospital,
Samutprakarn Province, Thailand

ABSTRACT

Objectives: Genu recurvatum is a common gait abnormality in ambulatory stroke survivors, often persisting into the chronic phase and causing problems such as knee pain or interfering with balance ability. While robotic gait training has shown benefits in subacute populations, its application in chronic stroke with longstanding knee hyperextension remains underreported. This study aim to report whether a systematically progressive robotic gait training program can reverse longstanding post-stroke genu recurvatum in a chronic stroke survivor

Case Presentation: We report the case of a middle-aged female, two years post-right middle cerebral artery infarction, who presented with persistent left knee hyperextension during the stance phase and fear of falling. She underwent a year-long outpatient-based robotic gait training program using the SensibleSTEP® end-effector device, followed by Body Weight Supported Treadmill Training (BWSTT). The training was based on the principle of "as much support as necessary, but as little as possible," with progressive adjustment of gait speed, step length, and body weight support. A speed challenge protocol was introduced after the patient achieved basic stance-phase control. Despite a mid-course setback due to spasticity, managed with a tibial nerve phenol block, the patient progressed to full prevention of knee hyperextension and achieved independent ambulation at low speed without the use of gait aids.

Conclusions: Carefully structured robotic gait training, incorporating progressive speed challenges, may help reverse chronic genu recurvatum even years after stroke. This case suggests that robotics can extend the therapeutic window for gait recovery in individuals with chronic stroke.

Keywords: case reports, stroke rehabilitation, knee, robotics, gait

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Introduction

Genu recurvatum, or knee hyperextension during the stance phase, is a common gait abnormality observed in individuals post-stroke, particularly among those with moderate to severe hemiparesis who retain ambulatory capacity. A large-scale observational study of 1,110 ambulatory stroke survivors reported a prevalence of genu recurvatum in approximately 19.5% of patients, with a subset experiencing knee pain and long-term joint stress, raising concerns over its biomechanical and functional implications.[1] Importantly, imaging studies of these patients reveal cartilage abnormalities not only in the paretic limb but also on the contralateral side, possibly due to compensatory overuse, underscoring the need for early biomechanical correction to prevent secondary joint damage.[2]

While some clinicians attribute recurvatum to spasticity of the quadriceps, particularly the rectus femoris, targeted nerve blocks have failed to improve knee extension control during stance, suggesting that isolated spasticity is not the sole driver of the abnormality.[3] Instead, appropriate proprioceptively guided co-contraction between hamstrings and quadriceps appears central to knee stabilization.

Several therapeutic approaches have been explored to mitigate genu recurvatum. Proprioceptive gait training, such as prowling exercises, has shown promising results in reducing hyperextension and improving swing-phase knee flexion.[4, 5] Orthotic interventions also play a significant role. For example, hinged soft knee orthoses[6] and articulated ankle-foot orthoses with calibrated plantarflexion resistance[7] can reduce hyperextension during stance. Robot-assisted gait training and treadmill-based therapies using pneumatic robotic knee-ankle-foot devices have demonstrated improvements in recurvatum angles, gait speed, and overall motor scores in patients with chronic stroke.[8]

Even though several of these methods show promising outcomes, it is generally believed that genu recurvatum in chronic stroke patients cannot be completely reversed. While the degree of hyperextension can be reduced, the abnormal gait pattern often persists to some extent.[8]

Robotic gait training devices are becoming increasingly prevalent in post-stroke rehabilitation programs. A systematic review and meta-analysis of randomized controlled trials concluded that electromechanical-assisted gait training

Correspondence to: Parit Wongphaet, MD, FRCPhysiatrT; Department of Rehabilitation Medicine, Samrong General Hospital, 1748 Soi Sukumvit 78, Samrong-Nuea, Muang, Samutprakarn 10270, Thailand; E-mail: spine.clinic@yahoo.com

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combined with physiotherapy increases the likelihood of achieving independent walking after stroke, compared to gait training without such devices.[9] The number needed to treat (NNT) to achieve one additional case of independent walking is eight. The most significant benefit is observed in patients within the first three months post-stroke, particularly in those who are initially non-ambulatory. These technologies provide high-intensity, repetitive training with real-time feedback and reproducible motion guidance—essential elements for promoting neuroplasticity and gait retraining.[10]

"SensibleSTEP" is an end-effector-type robotic gait training device that has received approval from the Thai Food and Drug Administration (Thai FDA). It is engineered to provide safe, adjustable body weight-supported training, with customizable gait speed, step length, and both vertical and horizontal support, accommodating individual patient needs. Unique to its design, SensibleSTEP provides continuous visual feedback on the timing and magnitude of weight shift through its dual moving footplates. While this type of system has been successfully used for gait rehabilitation in subacute, non-ambulatory stroke patients[11], its utility in chronic stroke—specifically for cases with genu recurvatum—remains undocumented. This absence of literature suggests a novel opportunity to explore its application in improving knee kinematics and stance phase control in ambulatory chronic stroke patients with persistent recurvatum. This case report is written in accordance with the CARE guideline checklists.

We have been using SensibleSTEP at our hospital for more than five years. When a patient is in the machine, they stand on two moving footplates. The changing position of the footplates forces the patient to continuously adjust the co-contraction between the quadriceps and hamstrings to match the changing vector of the ground reaction force. This task can be made easier by slowing the walking speed, prescribing a shorter step length, providing more horizontal (side-to-side) hip support, increasing vertical trunk bodyweight support, or allowing greater hand support. As the patient's skill improves—specifically when they can maintain stable knee control throughout the stance phase without buckling or hyperextension—these parameters are progressively and systematically adjusted to increase training difficulty step by step, allowing further improvement.

Successful reversal of recurvatum had been consistently observed in many cases at our hospital, sometimes even within a single session; however, because neither video recording nor joint-angle-based gait analysis was routinely performed, these outcomes were not suitable for publication. It was during the subsequent initiation of systematic video documentation that the current patient presented for treatment.

To our knowledge, no previous report has documented the complete reversal of chronic post-stroke genu recurvatum using robotic gait training. Given these gaps in the literature and our clinical observations, we hypothesized that a systematically progressive robotic gait training program—designed to optimize stance-phase knee control through adjustable footplate dynamics, modulated support, and speed-dependent challenge—could meaningfully reverse longstanding genu recurvatum even in the chronic phase after stroke. The objective of this case report is to describe the clinical course, training parameters, and outcomes of a chronic stroke survivor with persistent knee hyperextension who underwent this structured robotic gait training approach, and to illustrate its potential role in restoring more physiological knee kinematics beyond the conventionally accepted therapeutic window.

Patient information

The patient is a middle-aged female who experienced a large right middle cerebral artery (MCA) infarction two years prior to enrollment in the robotic gait training program. The case was presented to the Rehabilitation Medicine Department, Samrong General Hospital. She had no known comorbidities and had initially undergone approximately four months of conventional inpatient rehabilitation, which was discontinued due to a plateau in progress. An unsupervised home exercise regimen followed this.

At the time of evaluation, she was independent in all basic activities of daily living (ADLs). However, she had not returned to her previous occupation as an accountant due to persistent reading difficulty and dizziness. She ambulated with a tripod cane and reported low walking confidence and fear of falling. Her primary rehabilitation goal was to regain confidence and independence in community ambulation.

Clinical findings

At the time of assessment, the patient exhibited consistent hyperextension of the left knee during the stance phase of gait, as well as shortened stance duration on the paretic side. There was no evidence of joint contracture, and passive range of motion at all major lower extremity joints was preserved. Lower extremity muscle tone of the knee extensors, knee flexors, and ankle plantar flexors was slightly increased, with a score of 1+ on the Modified Ashworth Scale.

The patient could extend the knee and flex the hip against gravity and strong manual resistance, but the movement was partially limited to synergistic patterns. Selective dorsiflexion at the ankle was absent, indicating impaired distal motor control. Sensory examination demonstrated intact light touch and proprioception in both lower limbs, with no abnormalities in joint mobility or tactile sensation.

Passive range of motion assessment demonstrated no contracture of the ankle or knee joints, and no shortening of the gastrocnemius-soleus complex; the ankle could be positioned in dorsiflexion beyond 90 degrees with the knee either flexed or fully extended. Knee stability tests, including varus and valgus stress tests and anterior and posterior drawer tests, revealed no joint laxity. The genu recurvatum observed in this patient was painless and occurred consistently throughout early, mid, and late stance phases without

any sudden snapping into hyperextension. The abnor-mal knee angle was clearly distinguishable from the contra-lateral limb on visual inspection, and joint-angle measurements were subsequently quantified using Kinovea software as described in the diagnostic methods section. Functionally, the patient was able to perform sit-to-stand and stand-to-sit transitions independently, ambulate on level ground with a gait aid, and ascend and descend stairs using a step-to pattern while holding the handrail. Gait speed was not recorded, as the primary interest in this case was the reversal of knee recurvatum, and it was anticipated that walking velocity might not necessarily improve. At the same time, the patient concentrated on preventing hyperextension during gait. Gait endurance tests, such as the 6-minute walk test (6MWT), were not conducted.

Examination of the upper extremity revealed the absence of voluntary hand function and minimal active movement at the shoulder and elbow, restricted to full flexor and partial extensor synergistic patterns. Despite profound motor impairment, the thumb-finding test was normal, indicating preserved proprioceptive function at the shoulder, elbow, wrist, and thumb joints.

Functionally, the patient ambulated with a tripod cane but demonstrated a slow gait, characterized by cautious steps and a pronounced fear of falling. Despite being independent in all basic activities of daily living, she had not returned to her profession due to reading difficulty and persistent dizziness.

Neuropsychological testing[12] revealed severe visuospatial neglect. On the Rey-Osterrieth Complex Figure Copy test[13], the patient omitted nearly the entire left half of the figure and significantly distorted the right-sided features. (see figure 2a) Other cognitive domains, including memory, language, reasoning, executive function, self-control, and praxis, remained intact. The patient was able to engage meaningfully in rehabilitation planning.

Interpretation of timeline and training progression

This case illustrates an individualized, structured, adaptive, and progressive robotic gait rehabilitation process, guided by the principle emphasized by the late Professor Stefan Hesse, a pioneer of the world's first end-effector-type gait robot, that rehabilitation should offer "as much support as necessary, but as little as possible."[14] Over the course of the program, five key parameters were systematically adjusted in each session: walking speed, step length, vertical trunk support (body weight unloading), horizontal trunk (hip) support, and reliance on upper limb support (handrails). These were modified dynamically, either independently or in combination, according to the patient's evolving neuromotor capacity, as detailed in the training log (Appendix 1) and summarized graphically in Figure 1.

Timeline

Date	Clinical event / intervention
Late Mar 2024	Initial doctor visit: pre-training assessment.
Early Apr 2024(A)	First training session: patient able to prevent knee hyperextension in some steps at low speed (1.1 km/h) on SensibleSTEP with continuous use of hand-rail support.
Late Apr 2024	Doctor visit: no observable change in overground gait.
Late May 2024	Training log: improved knee control on SensibleSTEP up to 1.7 km/h; no hip support required; started speed challenge protocol.
Early July 2024(B)	Training log: full knee control up to speed 2.0 km/h on SensibleSTEP, start using "speed challenge protocol" in gait training at the eighth session.
Mid Jul 2024	Doctor visit: partial prevention of recurvatum during ground walking.
Mid Aug 2024(C)	Training log: change of training strategy, prioritizing top speed at 34th ses-sion.
Late Aug 2024	Doctor visit: 80% of ground steps recurvatum-free using a single cane.
Mid Oct 2024(D)	Training log: reached best performance on SensibleSTEP at 49th session, af-ter which the training parameter regressed for the subsequent four sessions
Late Oct 2024	Doctor visit: Increased ankle spasticity identified; patient cannot prevent knee hyperextension in the stance phase, even with a tripod cane.
Late Nov 2024	Doctor visit: Underwent phenol neurolytic block to the left tibial nerve.
Early Dec 2024(D)	Training log: Switched to BWSTT at speeds up to 0.3 km/h; good knee con-trol, but ankle inversion spasticity required hands-on assistance.
Early Dec 2024	Doctor visit: acute right psoas myalgia resolved thoroughly after a hot pack and gentle passive stretching.
Mid Jan 2025	Doctor visit: complete absence of knee hyperextension while walking with a tripod cane.
Late Feb 2025	Doctor visit: full control of recurvatum at low speed using a single cane.
Early Mar 2025	Training log: Completed the last session of training, which required therapist assistance for ankle stability; afterward, the subject was able to manage foot placement independently.
Late Apr 2025	Doctor visit: able to largely prevent recurvatum at low speed without gait aid.

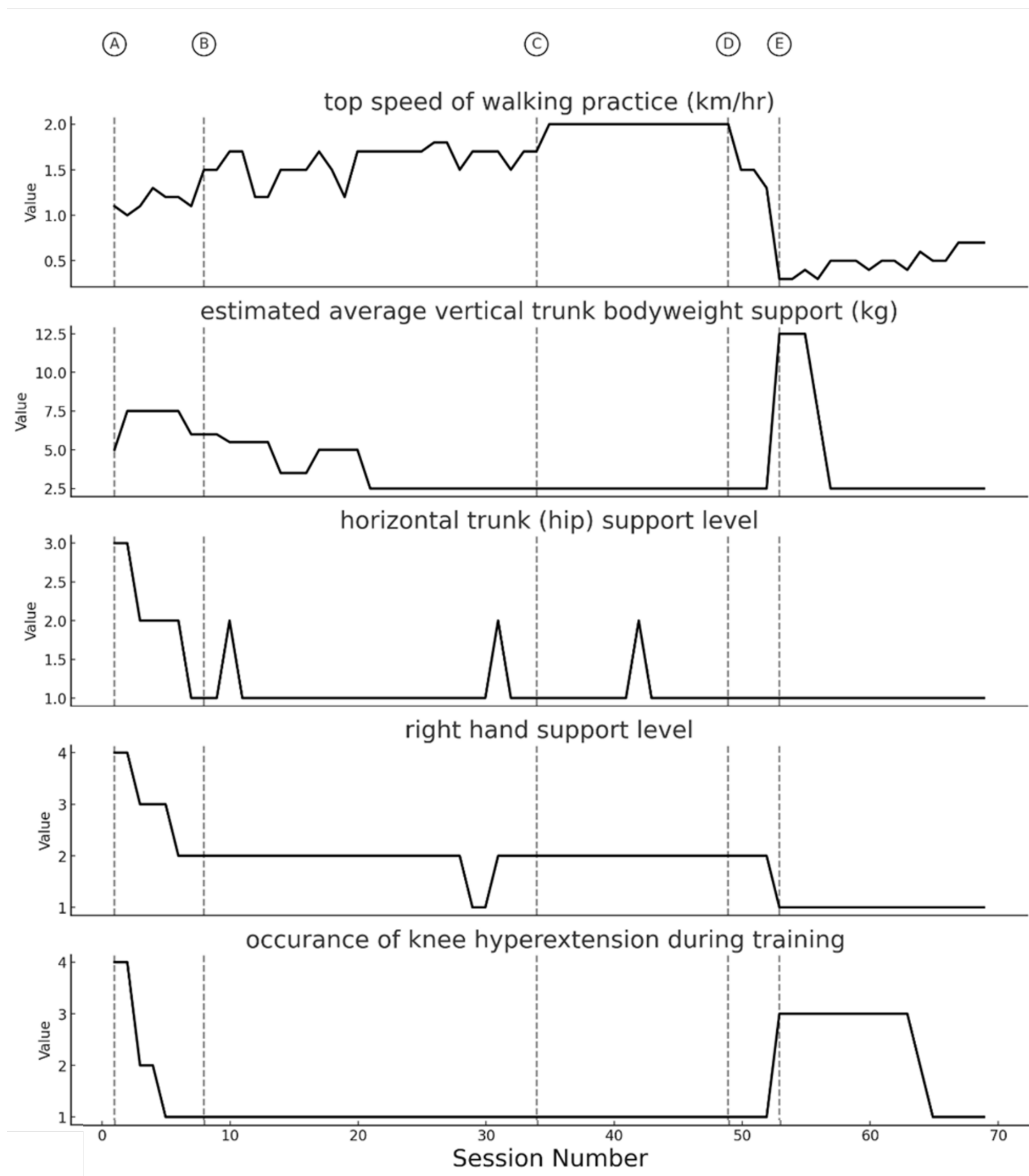

Figure 1. Display of Selected Training Parameters During the Course of Therapy

This graphic illustrates key training parameters recorded throughout the course of therapy, spanning 69 sessions. The first 52 sessions were conducted using the SensibleSTEP gait rehabilitation robot, while the remaining sessions, from session 53 to 69, transitioned to training with a body weight support treadmill training system (BWSTT).

During these sessions, various support and performance metrics were monitored. The horizontal trunk (hip) support level was rated on a scale where 3 indicates full mechanical support, 2 indicates partial support, and 1 indicates no support. The right hand support level was categorized as follows: 4 for constant hand holding, 3 for constant light touch, 2 for intermittent touch, and 1 for no hand support.

The occurrence of knee hyperextension during training was observed and rated with 4 indicating hyperextension occurred most of the time, 3 for about half of the time, 2 for less than half, and 1 indicating no hyperextension..

Several key milestones were annotated within the chart for reference:

(A) Session 1 marks the beginning of training with the SensibleSTEP gait robot.

(B) Session 8 represents the introduction of the speed challenge protocol.

(C) Session 34 highlights a shift in emphasis toward maximizing top walking speed.

(D) Session 49 indicates the peak of performance before a temporary decline due to ankle spasticity.

(E) Session 53 denotes the transition to body weight support treadmill training (BWSTT).

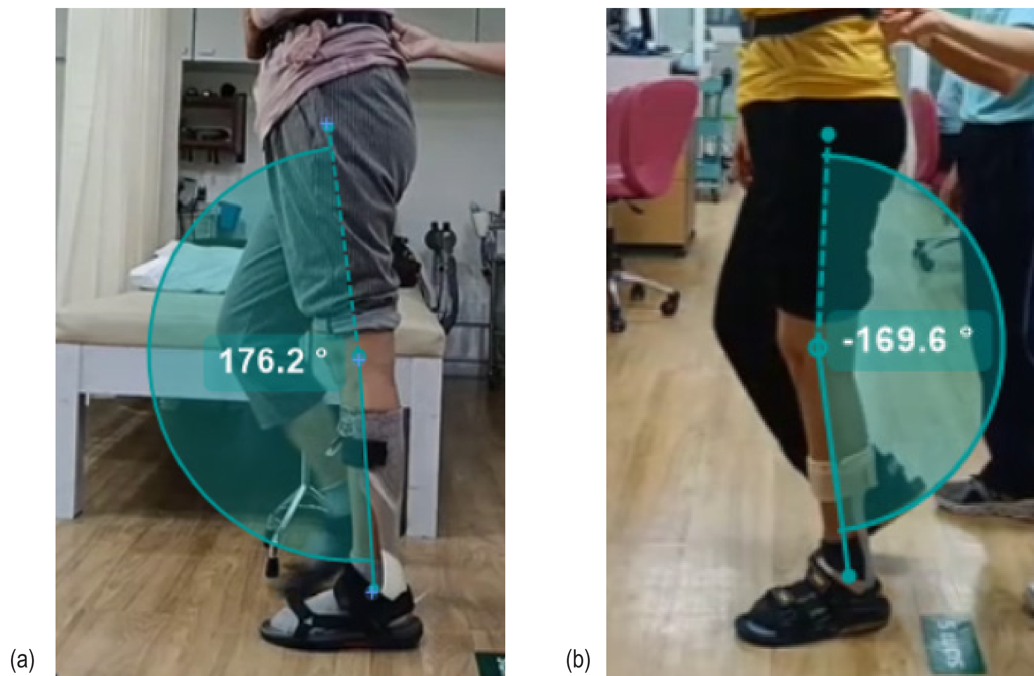

Figure 2. Side view of paretic knee during mid-stance pre- and post-treatment
Frames captured from overground gait video with minimal parallax. (a) Before treatment, using tripod cane, (b) After treatment, no gait aid

During the first eight sessions, the patient gradually developed the ability to stabilize the left knee and successfully prevent hyperextension during stance while practicing walking on the SensibleSTEP, though only at low walking speeds and with considerable support. Starting from the eighth session onward, the clinical team introduced the speed challenge protocol, a strategy developed to enhance motor adaptation and refine gait patterns. In each session, the therapist gently increased the speed of walking practice during 4-8 short bouts, pushing the speed up to the point where the patient could still maintain good knee control but required full concentration and perceived the task as challenging. Each high-speed bout lasted 10-15 seconds. After each bout, the speed was reduced to a “comfortable” pace, which was often higher than the patient’s previous baseline speed. This method enabled the patient to adapt to higher walking speeds and greater biomechanical demands within a short time, thereby maximizing the session-to-session acquisition of balance and gait skills through dynamic and responsive challenge adjustments. Such a training strategy has shown immediate benefits in improving gait quality in both early Parkinson’s disease[15] and ambulatory hemiparetic stroke patients.[16] Home exercises were neither prescribed nor recorded during this study.

Diagnostic assessment

No laboratory tests or imaging studies were used to assess this patient’s gait and balance. The diagnosis of post-stroke genu recurvatum and stance-phase knee instability was based entirely on clinical gait observation and on the changing parameters of the training setup.

Short video recordings were taken using unspecified mobile phones of convenience at the first and last training sessions during therapy visits. These included side-view videos of overground walking at the patient’s self-selected comfortable speed, with the patient intentionally attempting to control the knee and prevent hyperextension as much as possible. The videos clearly demonstrate progressive improvement in stance-phase knee control, starting from consistent hyperextension at every step—even while using a tripod cane—to complete prevention of hyperextension at every step without the use of any gait aid. A short video clip for this gait sequence is available online at https://archive.org/details/before-after-no-aid-compare.

Comprehensive training logs documenting these improvements are available in Appendix 1 and Appendix 2, respectively.

Figure 2 presents side-view images of the patient’s paretic knee during the mid-stance phase of gait, captured before and after the rehabilitation intervention. These images were extracted from a continuous video recording of overground walking. For each condition, a representative frame was selected based on minimal parallax error—specifically, the moment when the camera view was most tangential to the patient’s walking path and the knee joint was most clearly profiled. Image (a) shows the gait pattern prior to treatment, during which the patient relied on a tripod cane for support. Image (b) shows the same phase of gait following treatment, with the patient walking independently without any assistive device. These figures visually illustrate the changes in knee joint posture and stability during the stance phase resulting from the intervention.

Neuropsychological assessment revealed severe visuospatial neglect, confirmed by the Rey-Osterrieth Complex Figure Copy Test, which showed marked omission of elements on the left side and distortion of those on the right. However, despite this visual perceptual impairment, the patient did not exhibit any features of "pusher syndrome." There was no trunk inclination or postural bias in sitting, standing, transitions from sitting to standing, or during gait initiation[17] This suggests that the spatial perceptual difficulty was confined to external visual space, without involvement of the somesthetic sense or body schema.

At approximately five months into the training program, a marked improvement in visuospatial performance was observed. Although minor omissions and placement errors persisted, the severity of these deficits was greatly reduced. The patient's initial Rey-Osterrieth Complex Figure Copy performance is shown in Figure 3a, while the post-therapy performance is depicted in Figure 3b. For reference, the standard model figure provided for copying is shown in Figure 3c.

Furthermore, knee joint proprioception was intact, as was lower limb sensory function, reinforcing the conclusion that the genu recurvatum was not due to sensory loss. For these reasons, the gait abnormality was attributed primarily to impaired dynamic motor control of the paretic lower limb. Given the chronic stage of recovery and the clear clinical picture, no further diagnostic testing was deemed necessary.

Therapeutic intervention

The patient participated in a high-repetition, task-specific robotic gait training program, completing 69 sessions over a 12-month period. The primary rehabilitation objective was to restore stance-phase knee stability and reduce genu recurvatum. Training was delivered in two phases: initially with the SensibleSTEP end-effector robotic system, followed by Body Weight Supported Treadmill Training (BWSTT) once the maximum challenge level on SensibleSTEP was achieved.

Each session lasted 20 minutes. Initially, sessions included rest intervals; however, as endurance improved, the patient was able to achieve 20 minutes of continuous walking at a pace of 40-50 steps per minute, totaling approximately 800-1,000 steps per session. This volume exceeds typical step counts achieved in conventional therapy and meets criteria for intensive motor practice.

Training frequency was designed to promote skill acquisition and consolidation of stance-phase control, with the patient averaging 1.3 sessions per week over a 52-week period. A detailed overview of gait training progression is provided in Appendix 1.

Concurrently, the patient participated in an outpatient occupational therapy program focused on figure copying, constructional tasks, and graded visual field search activities, with a slow progression from simple to complex tasks. This program was discontinued after six months.

No additional rehabilitation interventions were administered beyond those described. Specifically, no tilt table training, passive stretching, or seated bench exercises were employed. Ground-based walking was occasionally included but limited to a few laps of approximately 10 meters per session, serving only as a minor adjunct to robotic gait training.

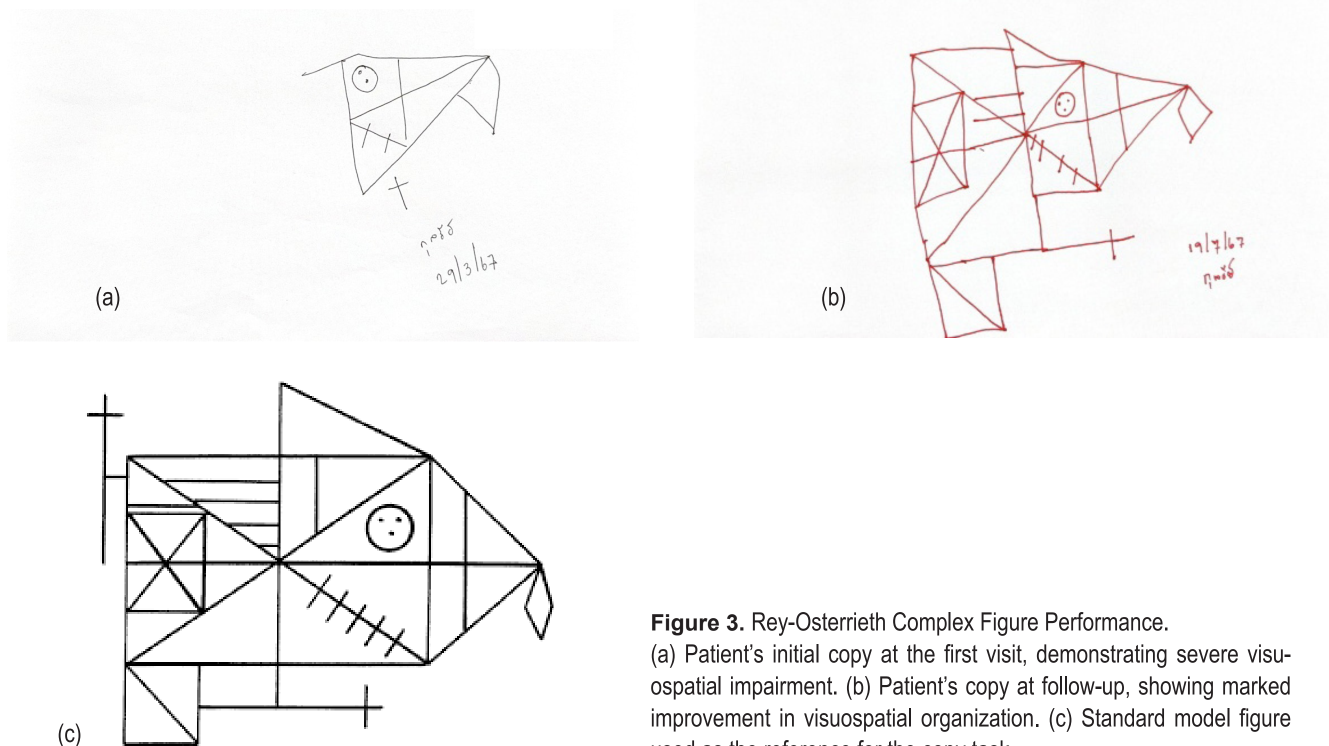

Figure 3. Rey-Osterrieth Complex Figure Performance.
(a) Patient's initial copy at the first visit, demonstrating severe visuospatial impairment. (b) Patient's copy at follow-up, showing marked improvement in visuospatial organization. (c) Standard model figure used as the reference for the copy task.

Follow-up and outcomes

A significant change in clinical status was noted during the October 2024 follow-up, approximately seven months into training: although resting tone was unchanged (Ashworth 1+), action-dependent ankle plantarflexion and inversion spasticity emerged, impairing knee control during overground walking. In response, a phenol neurolytic block was performed on the left tibial nerve in November. This intervention was supported by data from the training log, which showed a reduction in top walking speed from 2.0 km/h to 1.5 and 1.3 km/h in the sessions immediately preceding the block. This result underscores the sensitivity of robotic training metrics as indicators of gait and balance functional level.

The emergence of increased spasticity in this patient was most likely related to the heightened motor effort required during training to activate the knee-stabilizing musculature, particularly the quadriceps and hamstrings. Such sustained effort can increase excitability within central neuronal pools, especially at the spinal level. It is well recognized that high-effort motor tasks can provoke unintentional co-contractions in distant muscle groups, a phenomenon observed even in neurologically intact individuals and more prominently in those with prior central nervous system injury. In this case, years after the stroke, progressive training successfully enhanced knee control through improved agonist-antagonist co-activation; however, the same increase in descending drive and segmental excitability likely contributed to unintended overactivity of the calf muscles, resulting in action-dependent plantarflexion spasticity as a secondary complication.

By December 2024, approximately eight months into training, the patient had completed SensibleSTEP training close to its most challenging walking conditions—walking at 2.0 km/h with a 41 cm step length, no hip or hand support, and minimal vertical body weight support. It was evident that the patient was approaching a training ceiling within the SensibleSTEP system, where further increases in challenge were limited. Recognizing this, the clinical team made a deliberate decision to transition to Body Weight Supported Treadmill Training (BWSTT), which offered greater variability and higher levels of gait-specific demand beyond the capabilities of the end-effector robot.

Another brief minor setback occurred in early December 2024, when the patient developed acute psoas myalgia, likely due to the increased muscular demands of BWSTT. Moderate local tenderness over the muscle belly of the iliopsoas muscle at the proximal anterior thigh, just above the insertion point, was identified via manual palpation. Local treatment with a hot pack and stretching resolved the pain completely.

Following this, the patient continued to make steady progress. Notably, the gait training parameters had improved in parallel with the observed improvements in knee control during ground walking. She ultimately was able to walk without knee hyperextension and without gait aids at low speed. The treatment program was provided free of charge, as the research team believed the patient had potential for further recovery but remained uncertain about the extent of possible improvement. The patient expressed strong motivation to participate, willingly traveling for regular training sessions in the hope of enhancing her functional abilities. Verbal agreement to use her clinical information for a research case report was obtained at the outset, and written consent was secured upon completion of the training program.

The senior author (PW) serves as the hospital director and is also the director of the SensibleSTEP manufacturing company. This arrangement may introduce a potential conflict of interest; however, it also enabled the patient to undertake an extended course of therapy that would have been financially inaccessible otherwise. The outcome observed in this case may therefore be challenging to replicate in routine clinical practice—not because prolonged, progressive training is inherently ineffective, but because most chronic stroke survivors lack the financial means and logistical capacity to sustain long-term, high-frequency rehabilitation of this intensity.

Discussion

In our previous clinical experience, we have successfully reversed genu recurvatum gait in many stroke survivors, particularly among those with mild to moderate motor deficits. However, most patients with more severe deficits can participate in intensive training for only a limited duration—typically three to six months—due to financial or logistical constraints, regardless of whether they are still improving or have reached a plateau. This case is therefore relatively rare in that a highly chronic and severely affected patient was able to engage in consistent therapy over the span of an entire year. The outcome is particularly noteworthy given that the patient was more than two years post-stroke and had previously plateaued after conventional rehabilitation. In contrast to the typical trajectory of chronic stroke—where knee control abnormalities often persist, this case highlights the potential for targeted, parameter-driven robotic gait training to promote meaningful functional recovery even in the chronic phase, provided the intervention is sufficiently individualized and progressively scaled.

Although the outcomes in this case were not documented through laboratory-based gait measurements or formal clinical assessment scales, the magnitude of change was undeniable. The patient demonstrated a complete resolution of stance-phase knee hyperextension during overground walking, progressing from consistent recurvatum even with assistive devices to independent ambulation without gait aids. Improvements were corroborated by concurrent changes in robotic training parameters and observational video recordings, providing robust clinical evidence of genuine motor recovery.

Previous studies investigating interventions for genu recurvatum have generally shown reductions in hyperextension angles but rarely complete resolution of the abnormal gait pattern. A plausible explanation for the more favorable

outcome observed in this case lies in the longer duration, higher intensity, and individualized progression of training compared to most published protocols.

Beyond high repetition and task specificity, our program incorporated real-time, high-frequency biofeedback. Therapists provided continuous verbal cues during the stance phase, reinforcing correct knee stabilization patterns and correcting errors immediately. Moreover, training parameters were systematically titrated to maintain the patient within the “optimal challenge zone,” demanding enough to drive adaptation without provoking compensatory patterns or failure. Such an adjustment depends on the therapist’s decision. Thus, the effectiveness of training is influenced not only by the type of machine used but also by the therapist’s knowledge and skill. Young physiotherapists or new graduates may take a considerable amount of time to master this process, or may struggle to learn if they do not have the opportunity to work alongside experienced colleagues. To address this gap, we are developing an artificial intelligence (AI) system designed to assist therapists by suggesting training adaptations and explaining the rationale behind each recommendation. These advancements aim to support clinical decision-making and enhance the consistency and quality of rehabilitation outcomes.

Motor rehabilitation fundamentally relies on experience-driven neuroplasticity[18], and the clinical effects of robotic gait training are heavily dependent on the specific design features of the device used. Not all robotic systems afford the same opportunity for active engagement and error-based learning. For instance, modified end-effector devices with a saddle between the thighs can inhibit normal lateral weight shifting, thereby limiting dynamic knee control training. Similarly, two-point swing harness systems that oscillate the trunk forward and backward may disrupt natural lateral weight shifts and interfere with the development of dynamic balance. Rigid exoskeletons that impose pre-set limb trajectories further constrain the patient’s ability to generate and correct motor errors, an essential mechanism for retraining joint-specific dynamic knee stability. These design considerations underscore the importance of continuous, individualized adjustments to robotic training parameters—capabilities not uniformly available across all robotic systems.

In this study, the working definition of genu recurvatum relied on two clinically observable criteria: (1) apparent asymmetry visible to the naked eye when compared with the contralateral limb, and (2) apparent knee hyperextension, defined as any excursion beyond 180 degrees during any portion of the stance phase. Although this approach is less sensitive and less precise than gold-standard three-dimensional kinematic analysis, additional verification was performed using Kinovea, a freeware motion-analysis program. Anatomical markers were manually placed frame-by-frame, with the knee joint positioned at the visually estimated location of the lateral femoral epicondyle. Each sequence was reviewed to ensure that marker placement remained stable and did not drift or “bounce” relative to the underlying anatomical structures, and only sequences with minimal deviation were accepted for analysis. Despite the limitations inherent to two-dimensional video-based measurement, the convergence of clinical observation and training-performance data—illustrated in Figure 1 through the reduced frequency of hyperextension events, progressive increases in walking speed, and decreasing support requirements—strongly supports that the improvement in knee stabilization was genuine rather than an artifact of measurement constraints.

This case suggests that a complete reversal of chronic genu recurvatum is possible when rehabilitation integrates key motor learning principles, including prolonged duration, high repetition, task-specific practice, real-time therapist feedback, and dynamic modulation of task difficulty. Critically, the robotic system must permit active joint control and foster learning through trial and error. However, as a single-patient case report, these findings are not generalizable to the broader stroke population. To further validate these findings, future research should include prospective case series or randomized controlled trials incorporating quantitative gait analysis (e.g., marker-based or video-based systems), standardized functional outcome measures such as the Timed Up and Go (TUG), 6MWT, Fugl-Meyer Assessment, validated balance assessments, and spatiotemporal gait parameters. Including participants with varying levels of post-stroke severity will help delineate optimal patient selection criteria and protocol design.

It is important to acknowledge that the tibial nerve phenol block represented an unplanned co-intervention in this case. Although the injection contributed to a reduction in recurvatum by alleviating the newly emerged plantarflexor overactivity, its role should be interpreted within the broader clinical context. Prior to the intervention, training logs and video observations indicated that the patient was beginning to lose previously gained improvements in knee control, suggesting that the action-dependent increase in calf spasticity had become a disruptive factor in gait performance. Following the injection, stance-phase stability improved again, allowing training to resume its intended progression. Nevertheless, it is unlikely that the injection alone accounted for the overall restoration of knee stability; rather, the neurolytic block mitigated a secondary complication that had arisen during long-term training. The primary driver of recovery remained the structured, progressive motor retraining program, with the injection serving mainly to remove an interfering factor that hindered further gains.

Several noteworthy additional observations emerged from this case. First, changes in on-machine training parameters—such as walking speed, vertical unloading, and reliance on hand support—were detectable prior to observable improvements in overground gait through visual assessment. This result suggests that robotic training metrics may serve as earlier and more sensitive indicators of motor recovery than clinical gait observation. However, whether these pa-

rameters are more sensitive than instrumented temporal-spatial gait measures remains to be determined.

Second, progressive increases in training speed were systematically associated with reductions in vertical support, lateral trunk support, and handrail use, indicating coordinated improvement in dynamic balance and stance-phase control.

Third, the transition from Sensible STEP to BWSTT resulted in an immediate reduction in training speed, a marked increase in vertical support requirements (from 2.5 kg to 12 kg), and a transient reappearance of knee hyperextension during treadmill walking. These findings suggest that BWSTT imposes significantly greater biomechanical and motor control challenges compared to end-effector-based robotic systems.

Finally, the extent to which functional gains—such as improvements in gait speed and advanced balance performance—can be maximized and retained following the cessation of therapy remains an open question. Longitudinal follow-up at six- and twelve-months post-therapy will be critical to evaluating the durability of rehabilitation outcomes in this patient.

Patient perspective and informed consent

The patient reported that the therapy was highly beneficial, noting a marked increase in her confidence while walking and a reduction in her fear of falling. She also experienced improvements in her visual attention, which made daily activities more manageable. As a result, she felt able to resume work-related tasks and gradually regain a source of income, which further reinforced her sense of independence and quality of life. The patient provided written informed consent for the publication of this case report.

This case report was approved by the Medical Staff Organization of Samrong General Hospital, Samutprakarn Province, Thailand.

Conclusions

This case demonstrates that chronic post-stroke genu recurvatum, often considered irreversible, may be reversed entirely through individualized, progressive robotic gait training. The findings underscore the importance of long-duration, high-repetition, and parameter-driven therapy, which is supported by skilled clinical supervision. Future studies are warranted to confirm these results in larger cohorts and to establish clinical guidelines for patient selection and intervention protocols.

Conflict of interest declaration

The corresponding author (PW) is the director of Samrong General Hospital and of the company that manufactures the SensibleSTEP device. All other authors declare no conflicts of interest.

Generative AI declaration

Generative artificial intelligence tools were used in the preparation of this manuscript for grammar checking and for suggesting alternative sentence formulations. All original concepts, clinical interpretations, analytical reasoning, and the overall content structure were developed exclusively by the human authors.

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Data availability

To protect patient privacy, no medical records or additional personal data are shared. All essential data supporting the findings of this study are included within the manuscript, and selected gait video clips are available through the provided URL.

Author contributions

Parit Wongphaet: conceptualization, formal analysis, methodology, project administration, supervision, writing

Kittiphon Jitardhan: data curation, supervision, validation, visualization, writing.

References

1. Tani Y, Otaka Y, Kudo M, Kurayama T, Kondo K. Prevalence of genu recurvatum during walking and associated knee pain in chronic hemiplegic stroke patients: a preliminary survey. J Stroke Cerebrovasc Dis [internet] 2016[cited 2025 Aug 02];25(5):1153-7. Available from : https://pubmed.ncbi.nlm.nih.gov/20153279/ doi:10.1016/j.jstrokecerebrovasdis.2016.01.028
2. Li W, Li Y, Gao Q, Li W, Liu J, Wen Q, Jia S, et al. Change in knee cartilage components in stroke patients with genu recurvatum analysed by zero TE MR imaging. Sci Rep [Internet]. 2022 [cited 2025 Aug 02] ;12(1):3751. Available from : https://pubmed.ncbi.nlm.nih.gov/35260668/ doi:10.1038/s41598-022-07817-w
3. Gross R, Delporte L, Arsenault L, Revol P, Letevre M, Clevenot D, et al. Does the rectus femoris nerve block improve knee recurvatum in adult stroke patients? A kinematic and electromyographic study. Gait Posture. [internet] 2014 [cited 2025 Aug 02] ;39(2):761-6. Available from : https://pubmed.ncbi.nlm.nih.gov/24286615/ doi:10.1016/j.gaitpost.2013.10.008
4. Geerars M, Minnaar-van der Feen N, Huisstede BMA. Treatment of knee hyperextension in post-stroke gait: a systematic review. Gait Posture. [internet] 2022 [cited 2025 Aug 02] ;91:137-48. Available from : https://pubmed.ncbi.nlm.nih.gov/34695721/ doi:10.1016/j.gaitpost.2021.08.016

5. Dalal KK, Joshua AM, Nayak A, Mithra P, Misri Z, Unnikrishnan B. Effectiveness of prowling with proprioceptive training on knee hyperextension among stroke subjects using videographic observation—a randomised controlled trial. Gait Posture. [internet] 2018 [cited 2025 Aug 02] ;61:232-7. Availble from https://pubmed.ncbi.nlm.nih.gov/34695721/ doi:10.1016/j.gaitpost.2018.01.018
6. Portnoy S, Frechtel A, Raveh E, Schwartz I. Prevention of genu recurvatum in poststroke patients using a hinged soft knee orthosis. PM R. [internet] 2015 [cited 2025 Aug 02] ;7(10):1042-51. Available from : https://pubmed.ncbi.nlm.nih.gov/27136122/ doi:10.1016/j.pmrj.2015.04.007
7. Kobayashi T, Orendurff MS, Singer ML, Gao F, Daly WK, Foreman KB. Reduction of genu recurvatum through adjustment of plantarflexion resistance of an articulated ankle-foot orthosis in individuals post-stroke. Clin Biomech (Bristol). [internet] 2016 [cited 2025 Aug 02] ;35:81-5. Available from : https://pubmed.ncbi.nlm.nih.gov/27136122/ doi:10.1016/j.clinbiomech.2016.04.011
8. Takahashi Y, Okada K, Noda T, Teramae T, Nakamura T, Haruyama K, et al. Robotized knee-ankle-foot orthosis-assisted gait training on genu recurvatum during gait in patients with chronic stroke: a feasibility study and case report. J Clin Med [Internet]. 2023 [cited 2025 Aug 02] ;12(2):415. Available from : https://pubmed.ncbi.nlm.nih.gov/36675345/ doi:10.3390/jcm12020415
9. Mehrholz J, Thomas S, Kugler J, Pohl M, Elsner B. Electromechanical-assisted training for walking after stroke. Cochrane Database Syst Rev [Internet]. 2020 [cited 2025 Aug 02] ;10(10):CD006185. Available from : https://pubmed.ncbi.nlm.nih.gov/36675345/ doi:10.1002/14651858.CD006185.pub5
10. Kwakkel G, Stinear C, Essers B, Munoz-Novoa M, Branscheidt M, Cabanas-Valdis R, et al. Motor rehabilitation after stroke: European Stroke Organisation (ESO) consensus-based definition and guiding framework. Eur Stroke J [Internet]. 2023 [cited 2025 Aug 02] ;8(4):880-94. Available from : https://pubmed.ncbi.nlm.nih.gov/37548025/ doi:10.1177/23969873231191304
11. Chanubol R, Wongphaet P, Panichareon L, Chavanich N. Gait rehabilitation in subacute hemiparetic stroke: robot-assisted gait training versus conventional physical therapy. ASEAN J Rehabil Med [internet]. 2015 Nov. 10 [cited 2025 Aug 02] ;22(2):42-50. available from: https://he01.tci-thaijo.org/index.php/aseanjrm/article/view/42331
12. Wongphaet P, Chanubol R, Phakdepiboon T, Vongpipatana S, Smithnaraseth D, Srisilpa K, et al. Mind matters: a practical bedside clinical neuropsychology handbook. 1st ed. Bangkok: Samrong General Hospital; 2025.
13. Vongpipatana S, Chokkhatiwat K, Wongphaet P. A comparison between Rey-Osterrieth Complex Figure Copying Test versus a combined battery of five tests in patients with right hemispheric stroke. J Thai Rehabil Med [Internet]. 2017[cited 2025 Aug 02] ;27(1):25-9. Available from : https://he01.tci-thaijo.org/index.php/aseanjrm/article/view/68275 DOI:10.14456/jtrm.2017.6
14. Hesse S. Lokomotionstherapie: ein praxisorientierter Überblick. 1st ed. München: Pflaum Verlag; 2008. 131p.
15. Pohl M, Rockstroh G, Rückriem S, Mrass G, Mehrholz J. Immediate effects of speed-dependent treadmill training on gait parameters in early Parkinson's disease. Arch Phys Med Rehabil .[internet] 2003[cited 2025 Aug 02] ;84(12):1760-6. Available from : : https://pubmed.ncbi.nlm.nih.gov/14669180/ doi:10.1016/s0003-9993(03)00433-7
16. Pohl M, Mehrholz J, Ritschel C, Rückriem S. Speed-dependent treadmill training in ambulatory hemiparetic stroke patients: a randomized controlled trial. Stroke. [internet] 2002 [cited 2025 Aug 02] ;33(2):553-8. Available from: https://pubmed.ncbi.nlm.nih.gov/11823669/ doi:10.1161/hs0202.102365
17. Karnath H-O, Broetz D. Understanding and treating "pusher syndrome". Phys Ther. [internet] 2003 [cited 2025 Aug 02] ;83(12):1119-25. Available from : https://pubmed.ncbi.nlm.nih.gov/14640870/ doi:10.1093/ptj/83.12.1119
18. Nudo RJ. Recovery after brain injury: mechanisms and principles. Front Hum Neurosci [Internet]. 2013 [cited 2025 Aug 02] ;7:887. Available from : https://pubmed.ncbi.nlm.nih.gov/24399951/ doi:10.3389/fnhum.2013.00887