

Abdominal muscle transcutaneous electrical nerve stimulation for postoperative neurogenic claudication in lumbar spinal stenosis: a case report using kinesthetic illusion

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Case Report

Keywords:

Posted Date: October 5th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10731241/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background

Pain and gait impairment associated with neurogenic claudication (NC) may persist in patients with lumbar spinal stenosis (LSS) even after decompressive surgery. Dynamic sensorimotor alterations during walking may contribute to these impairments. In this case report, we focused on kinesthetic illusion as an exploratory indicator of altered afferent sensory function and describe the clinical course of transcutaneous electrical nerve stimulation (TENS) applied to the abdominal muscles.

Case presentation

The patient was a man in his 70s who had undergone four-level laminoplasty spanning L1/2 to L4/5 and presented with NC characterized by pain over the lateral aspect of the left lower leg. At the initial assessment, pain rated 8/10 on the Numerical Rating Scale (NRS) limited his walking distance during the 6-minute walk test (6MWT) to 80 m. At that time, an interlimb difference was observed in the kinesthetic illusion of ankle plantarflexion elicited by stimulation of the tibialis anterior (unaffected/affected limb: 4/10). During a subsequent 6MWT performed with TENS applied to the abdominal muscles, pain was rated 3/10, walking distance was 95 m, and the post-walking interlimb difference in the TA-evoked kinesthetic illusion was smaller than that observed after walking without TENS. The patient underwent walking practice combined with abdominal-muscle TENS for 14 days, together with therapeutic exercise. At the outcome assessment, the 6MWT performed without TENS resulted in an NRS pain score of 1/10 and a walking distance of 150 m; the TA-evoked kinesthetic illusion showed no pre-to-post 6MWT change (unaffected/affected limb: 7/10 to 7/10).

Conclusions

In this patient, abdominal-muscle TENS during walking was temporally associated with lower NC-related pain, greater walking distance, and a smaller post-walking interlimb difference in TA-evoked kinesthetic illusion. Over the 14-day intervention, pain and walking capacity also improved. These findings provide a foundational hypothesis for conducting research that examines the sensorimotor function of patients with LSS using sensory measures, spinal kinematics, and electrophysiological outcomes.

Introduction

Lumbar spinal stenosis (LSS), which predominantly manifests as lower-extremity muscle weakness, sensory disturbance, and neurogenic claudication (NC), is classified as central, lateral, or combined stenosis [1]. Among these phenotypes, lateral stenosis is more frequently associated with severe narrowing at the L4/5 level than are the other phenotypes [2] and has been reported to be particularly prone to neuropathic pain [3].

The pathophysiology of LSS is considered to involve anatomical factors, such as compression of the spinal canal or nerve roots; physiological factors, including neural dysfunction secondary to neural ischemia; and kinematic factors, such as increased mechanical loading within the spinal canal associated with elevated epidural pressure during lumbar extension [4]. Although surgical decompression may ameliorate these factors, pain and gait disturbance related to NC reportedly persist postoperatively in approximately 40% of patients [5]. Moreover, associations between clinical indices, such as the Oswestry Disability Index (ODI) and walking capacity, and radiological findings on magnetic resonance imaging have been shown to be limited [6–8]. Collectively, these findings suggest that postoperative functional impairment cannot be adequately explained by static structural abnormalities alone and that dynamic functional impairments arising during walking warrant consideration.

Spinal stability is thought to be maintained through interactions among passive supporting tissues, the paraspinal musculature, and the nervous system that integratively regulates these components (i.e., sensorimotor function) [9]. These interactions facilitate coordinated spinal posture, stability, and movement under dynamic conditions. Accordingly, the manifestation of NC may involve not only mechanical nerve-root entrapment but also impaired sensorimotor function.

In the present report, we focused on kinesthetic illusion as a means of detecting such functional changes. Kinesthetic illusion is the perception of joint movement in the direction that would lengthen the vibrated muscle [10]. Because this phenomenon arises through central nervous system integration of afferent input from multiple proprioceptors, including muscle spindles, it may reflect the functional integrity of afferent sensory input. In particular, assessment of kinesthetic illusion in muscles with clearly delineated segmental innervation may provide an indirect means of detecting walking-induced changes in nerve-root function.

We therefore hypothesized that walking-related changes in relative kinesthetic illusion ratings might accompany the exacerbation of NC in a patient with postoperative LSS. We also focused on transcutaneous electrical nerve stimulation (TENS) as an intervention targeting sensorimotor function. Previous studies have primarily applied stimulation to the lumbar musculature; however, the evidence regarding its effectiveness remains inconclusive [11, 12]. Conversely, patients with lumbar instability have been reported to exhibit diminished coordinated activation of the abdominal musculature [13, 14], and TENS has been proposed to modulate motor function through sensory input [15] and might influence sensorimotor control.

This report describes the clinical course of a patient with residual NC after surgery for LSS. We conducted an exploratory assessment using relative kinesthetic illusion ratings and descriptively examined changes observed during and after a multimodal physical therapy program that included abdominal-muscle TENS. This case report was prepared in accordance with the CARE guidelines [16].

Case description

Patient history and system review

A man in his 70s who was independent in activities of daily living and employed as a plumber (height, 157.5 cm; weight, 67 kg; body mass index, 27 kg/m²) presented to a previous hospital with a chief complaint of difficulty walking. Four years earlier, he had sought medical attention for foot drop and had been diagnosed with LSS. Although surgery had been proposed at that time, he preferred conservative management and used a soft ankle support. On the current admission, he underwent four-level laminoplasty for lumbar spinal stenosis at L1/2, L2/3, L3/4, and L4/5. Rehabilitation commenced on postoperative day 1 with the patient wearing a Damen-type corset, and he was transferred to our hospital on postoperative day 31 (Fig. 1). At the time of transfer, acetaminophen (Calonal) 200 mg/day had been prescribed for pain management.

Physical therapy examination

Physical therapy commenced on the day of admission. The patient stated, *"I can only walk about 20 m; I cannot go any farther, and I cannot lift my left foot,"* and expressed a desire *"to be able to walk more comfortably."* A physical therapy assessment was therefore undertaken to identify factors associated with his mobility limitation. Guided by the International Classification of Functioning, Disability and Health (ICF), the examination of impairments included orthopedic tests (Thomas and Kemp tests) and Manual Muscle Testing (MMT). Activity limitations were evaluated using the ODI and the 6-minute walk test (6MWT). Lower-extremity pain after the 6MWT was rated using the Numerical Rating Scale (NRS). As an exploratory assessment of changes in afferent sensory function associated with NC, kinesthetic illusion was also examined before and after the 6MWT.

For the kinesthetic illusion examination, the patient sat upright with both feet unsupported and elevated from the floor, and vision was occluded. The stimulation sites were the musculotendinous junction of the tibialis anterior (TA) and the Achilles tendon. A vibratory stimulation device (MD01, Thrive) was used to deliver stimulation at 91.7 Hz (High mode) for 20 s. TA stimulation thereby elicited an illusion of plantarflexion, whereas Achilles tendon stimulation elicited an illusion of dorsiflexion. Illusion intensity was evaluated using the NRS: the limb in which the illusion was perceived most intensely was assigned a score of 10, and the contralateral limb was rated relative to that reference. In this report, the limb exhibiting foot drop and pain was defined as the affected limb, whereas the right lower extremity was defined as the unaffected limb (Fig. 2).

To examine the inter-rater reliability of this test, a preliminary investigation was conducted in 10 healthy adults (5 men and 5 women; age, 24.8 ± 3.91 years). The intraclass correlation coefficients (2,1) and (2,3) were 0.54 and 0.70, respectively, indicating moderate inter-rater reliability [17].

Physical therapy evaluation

The results of the physical therapy examination are presented in Table 1. The severity of activity limitation, assessed using the ODI, was 38%, corresponding to moderate disability. Because pain-related mobility limitation was identified as the predominant concern, the 6MWT was performed to characterize it. During the test, the patient demonstrated the flexed-trunk gait pattern described by Igawa et al. [18] and developed pain rated 8/10 over the lateral aspect of the left lower leg. Walking distance was limited to 80 m (Fig. 3).

Table 1
Results of the physical therapy examinations and measurements

Assessment/Measurement		Initial assessment (Day 1)	Interim assessment (Day 7)	Final assessment (Day 14)
ODI (%)		38	38	34
NRS (unaffected/affected limb)	At rest	2	1	1
Kemp test (unaffected/affected limb)		-/∅	-/∅	-/∅
Thomas test (unaffected/affected limb)		∅/∅	∅/∅	∅/∅
MMT (grade) (unaffected/affected limb)	Trunk flexor muscles	4	4	5
	Trunk extensor muscles	3	3	3
	Gluteus maximus	3/3	4/3	4/4
	Tibialis anterior	5/0	5/0	5/0
6MWT(m) / NRS	Without TENS	80m/8	120m/2	150m/1
	With TENS	95m/3	140m/1	155m/1
Kinesthetic illusion test (before → after 6MWT)* (unaffected/affected limb)	TA	4/10 → 10/10	6/10 → 9/10	7/10 → 7/10
	Achilles tendon	10/3 → 10/3	10/7 → 10/7	10/8 → 10/7
Kinesthetic illusion test (before → after 6MWT)* with abdominal muscle TENS (unaffected/affected limb)	TA	4/10 → 6/10	6/10 → 8/10	6/10 → 6/10
	Achilles tendon	10/4 → 10/3	10/7 → 10/7	10/8 → 10/8
Abbreviations: ODI, Oswestry Disability Index; NRS, Numerical Rating Scale; MMT, Manual Muscle Testing; 6MWT, 6-minute walk test; TENS, transcutaneous electrical nerve stimulation; TA, tibialis anterior.				

The impairment assessment revealed iliopsoas shortening, as indicated by a positive Thomas test, and weakness of the gluteus maximus corresponding to MMT grade 3. The Kemp test was negative. Given that the patient had undergone surgical decompression and had a negative Kemp test, we considered that dynamic functional changes arising during walking, rather than residual anatomical factors, might contribute to his NC.

We compared kinesthetic illusion ratings before and after the 6MWT to characterize walking-related changes in the relative interlimb perceptual pattern. Kinesthetic illusion elicited by Achilles tendon stimulation remained essentially unchanged (unaffected/affected limb: 10/3 to 10/3). In contrast, the plantarflexion illusion elicited by TA stimulation diminished in the affected limb after the 6MWT, with a concomitant reduction in the interlimb difference (unaffected/affected limb: 4/10 to 10/10). The patient likewise stated, "It feels weaker than it did before." The temporal concurrence of NC exacerbation, the altered relative rating pattern, and the patient's subjective report generated a hypothesis of possible shared L5 nerve-root or afferent involvement.

We subsequently conducted a 6MWT while administering TENS to the lower rectus abdominis muscles (ESPURGE, Ito Co., Ltd.; stimulation method, 2 × bipolar; intensity, sensory threshold; frequency, 100 Hz; pulse width, 250 µs; ON/OFF, continuous). Pain over the lateral aspect of the left lower leg was rated 3/10 on the NRS, and the walking distance was 95 m. The TA-evoked kinesthetic illusion was rated 6/10 in the unaffected/affected limbs, indicating that the change in interlimb asymmetry was attenuated relative to walking without TENS. These observations were used to formulate a provisional treatment rationale concerning trunk-related sensorimotor function.

Evaluation summary and functional diagnosis

The principal problem associated with this patient's mobility limitation was pain during walking attributable to NC. Within the clinical reasoning process, altered trunk sensorimotor function and afferent processing were treated as provisional hypotheses.

Although weakness of the gluteus maximus (ICF code: b730) and shortening of the iliopsoas (ICF code: b710) were also present, the within-session observation of less pain and a longer walking distance during the 6MWT with abdominal-muscle TENS led us to prioritize a trial of treatment directed toward trunk sensorimotor control (ICF code: b760).

Prognosis

In general, the proportion of patients with LSS who experience persistent numbness, pain, or walking impairment ranges from 15% to 30% [19]. Moreover, a previous report indicated that foot drop improved in patients whose preoperative TA strength corresponded to MMT grade 2 and whose paralysis had persisted for less than 3 months [20]. In light of the 4-year history of foot drop, recovery of ankle function was considered less likely. During the initial sequential assessment, less pain and a longer walking

distance were observed during the TENS condition than during the preceding no-TENS condition. Accordingly, treatment addressing the hypothesized trunk sensorimotor dysfunction was selected as one component of a physical therapy program.

Intervention

Japanese physical therapy guidelines for impaired back function recommend combining physical modalities and therapeutic exercise in accordance with the patient's clinical condition [21]. Based on the physical therapy assessment, we therefore implemented an intervention combining TENS and therapeutic exercise. Specifically, the patient performed push-off practice while receiving abdominal-muscle TENS (10 repetitions × 5 sets) and independent walking practice totaling 200 m. These exercises were intended to improve trunk alignment and coordinated motor control during walking. Additional interventions comprised the draw-in maneuver, gluteus maximus strengthening, and iliopsoas stretching. Treatment was delivered in three 60-min sessions per day for 14 days (Fig. 4). The TENS parameters were identical to those used during the 6MWT at the assessment.

Outcomes

At the interim assessment 7 days after the intervention commenced, pain over the lateral aspect of the left lower leg after the 6MWT had decreased from 8/10 to 2/10 on the NRS, and walking distance had increased from 80 to 120 m. The plantarflexion illusion elicited by TA stimulation (unaffected/affected limb) changed from 6/10 to 9/10, demonstrating a reduction in the interlimb difference. The intervention was therefore continued without modification.

At the outcome assessment after 14 days, pain over the lateral aspect of the left lower leg after the 6MWT had decreased to 1/10 on the NRS, and walking distance had increased to 150 m. The patient's gait pattern also changed from a flexed-trunk pattern to a more extended posture (Fig. 3). He stated, "My leg still feels heavy, but the pain is almost gone." At this time, differences in post-6MWT pain and walking distance between conditions with and without abdominal-muscle TENS had diminished, and changes in the outcome measures had generally stabilized.

Discussion

The first hypothesis generated by this report is that walking-related changes in relative kinesthetic illusion ratings may accompany NC symptoms. Kinesthetic illusion arises when proprioceptive information elicited by vibration ascends through the dorsal columns of the spinal cord and is integrated and processed within the cerebral cortex. Furthermore, latency abnormalities in somatosensory evoked potentials have been reported in patients with LSS who exhibit NC [22, 23]. In the present patient, the intensity of the TA-derived kinesthetic illusion diminished after walking, potentially reflecting a walking-induced alteration in afferent sensory function. The parallel observation of reduced NC-related pain and increased kinesthetic illusion intensity further supports this interpretation.

The second hypothesis is that abdominal-muscle TENS may have been associated with reduced NC and improved walking capacity. In general, sensory-threshold TENS applied to the abdominal musculature is unlikely to stimulate a nerve trunk directly, which would require a relatively high stimulation intensity [24]. Consequently, the changes observed in this patient are difficult to explain solely in terms of a quantitative increase in motor output. By contrast, impaired trunk proprioception has been reported in patients with LSS [25], and such abnormalities may persist postoperatively [26]. TENS may influence proprioceptive input by altering muscle spindle sensitivity and through stochastic resonance [27, 28], and it may likewise have contributed to improved motor performance in this patient by modifying sensory input.

This report has several limitations. First, trunk proprioception, abdominal-muscle activation, spinal kinematics, and electrophysiological responses were not directly assessed; consequently, the proposed afferent and trunk sensorimotor mechanisms remain unverified. Second, kinesthetic illusion was scored using a relative scale in which the more intense limb was assigned 10 at each assessment. This normalization precludes quantification of absolute longitudinal or between-condition changes. Third, neither the patient nor the therapist was blinded to TENS, and the stimulation was perceptible, introducing the possibility of expectancy and observer effects. Fourth, this single-case report included no cross-over or single-case experimental design. Because the TENS-assisted 6MWT followed the no-TENS 6MWT, condition effects cannot be separated from fatigue, recovery during rest, familiarization, pacing variation, or other order effects. Fifth, the intervention comprised TENS, push-off and walking practice, draw-in exercise, gluteal strengthening, and iliopsoas stretching delivered in three 60-min sessions per day. These concurrent treatments, analgesic medication, and spontaneous postoperative recovery prevent attribution of the 14-day changes to TENS. Finally, observations from one patient cannot be generalized to the broader postoperative LSS population. Accordingly, the present findings should be regarded as descriptive and hypothesis-generating only.

Conclusion

In this single patient with residual NC after surgery for LSS, pain decreased and 6MWT distance increased over 14 days of physical therapy that included abdominal-muscle TENS. Furthermore, the TENS condition coincided with less pain, a longer walking distance, and a different relative kinesthetic illusion pattern than the preceding no-TENS condition. These findings provide a foundational hypothesis for conducting research that examines the sensorimotor function of patients with LSS using sensory measures, spinal kinematics, and electrophysiological outcomes.

Abbreviations

LSS
Lumbar spinal stenosis
NC
neurogenic claudication

ODI
Oswestry Disability Index
TENS
transcutaneous electrical nerve stimulation
ICF
International Classification of Functioning
Disability and Health,MMT,Manual Muscle Testing
6MWT
6-minute walk test
NRS
Numerical Rating Scale
TA
tibialis anterior.

Declarations

Consent for publication

Patient was agreed for publication.

Competing interests

The authors have no conflict of interest to report.

Author Contribution

T.S.: Conceptualization, Methodology, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Project administration

A.T.: Conceptualization, Methodology, Writing - Review & Editing,

K.F.: Conceptualization, Writing - Original Draft, Supervision

Acknowledgement

The authors would like to thank the patient and him family for participating in this study and the esteemed staff for their invaluable contributions.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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Figures

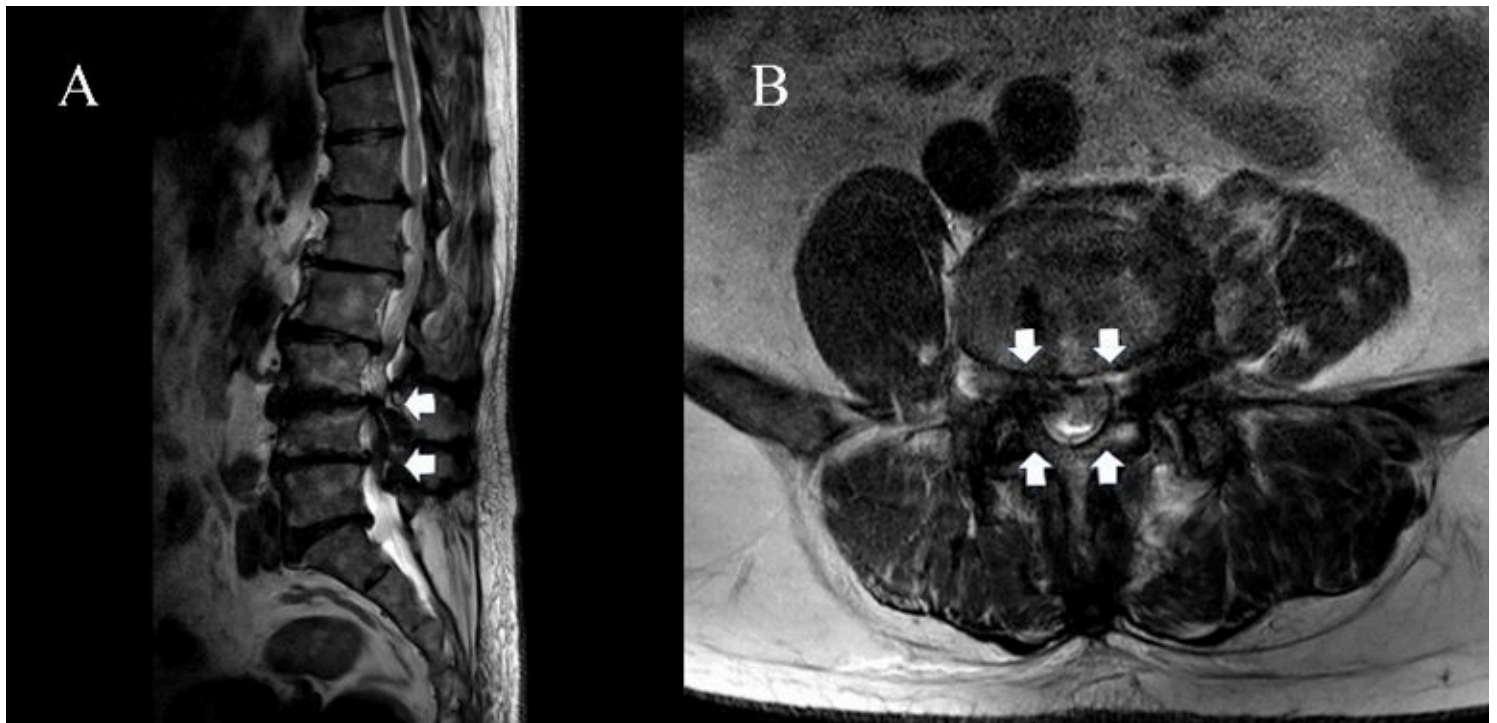


Figure 1

Preoperative magnetic resonance images of the lumbar spine.

(A) Sagittal image showing spinal canal stenosis at L3/4 and L4/5.

(B) Axial image showing bilateral hypertrophy of the ligamentum flavum and lateral recess stenosis.



Figure 2

Kinesthetic illusion test.

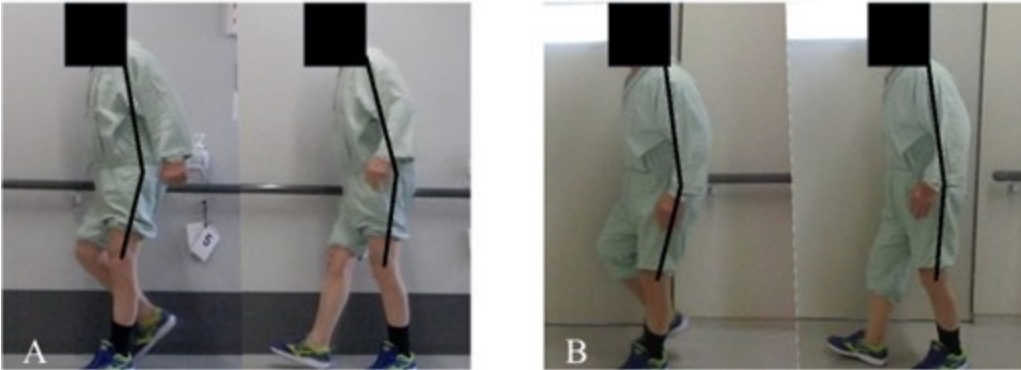


Figure 3

Observational gait analysis.

(A) Initial assessment showing a flexed-trunk gait pattern throughout the gait cycle.

(B) Outcome assessment showing a change from a flexed-trunk gait pattern to a more extended trunk posture throughout the gait cycle.



Figure 4

Push-off practice with concurrent transcutaneous electrical nerve stimulation of the abdominal muscles.

Supplementary Files

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