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CASE REPORT



Stimulation-associated motor and functional improvement after epidural spinal cord stimulation in chronic spinal cord injury secondary to spinal ependymoma: A case report

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ABSTRACT

Context: Chronic spinal cord injury (SCI) secondary to spinal tumors may cause persistent motor and sensory dysfunction despite surgical treatment and rehabilitation. Ependymomas are the most common intramedullary spinal tumors in adults, but long-standing neurological deficits after tumor surgery are difficult to treat.

Findings: We report a 51-year-old man with chronic SCI after thoracic spinal ependymoma surgery performed in 2000. He had persistent right-predominant lower-extremity weakness, sensory loss below T10, limited walking endurance, and cane-dependent ambulation. EES was performed in October 2024 using a 32-contact paddle lead positioned over T12-L1. Motor-oriented programs were predominantly delivered at 40 Hz (approximately 3–4 mA; pulse width approximately 300 microseconds) and selected according to activity. The patient progressed from AIS C to AIS D, while SCIM III increased from 84 at baseline to 88, 96, 98, and 98 at 3, 6, 9, and 12 months, respectively. At the latest follow-up, AIS D was maintained with stimulation OFF and ON, while active stimulation provided additional facilitation of selected lower-extremity muscles, particularly ankle dorsiflexion.

Conclusion/Clinical relevance: This case suggests that individualized EES may be associated with clinically meaningful motor and functional improvement even decades after SCI secondary to spinal ependymoma surgery. Longitudinal gains persisted with stimulation OFF, while stimulation ON provided additional task-dependent motor facilitation.

KEYWORDS

Epidural spinal cord stimulation; spinal cord injury; ependymoma; neuromodulation; functional improvement

Introduction

Spinal cord injury (SCI) may result from diverse etiologies, ranging from traumatic mechanisms to non-traumatic conditions such as spinal cord tumors. Among intramedullary spinal tumors in adults, ependymomas represent the most frequently encountered pathological type and account for a large proportion of adult intramedullary lesions (1). Surgical resection remains the primary therapeutic approach for these tumors. Nevertheless, neurological deficits may persist after surgery due to chronic spinal cord compression, tumor-related damage to neural tissue, or intraoperative manipulation.

Although advances in microsurgical techniques have helped make tumor resection safer, many patients continue to have long-term neurological impairment following surgery. Persistent motor weakness, sensory deficits, and autonomic dysfunction are commonly reported outcomes and may persist over time despite rehabilitation interventions.

In recent years, neuromodulation techniques have been increasingly investigated as possible treatment approaches for patients with chronic SCI. Among these approaches, epidural spinal cord stimulation (EES) has attracted considerable interest because of its potential to modulate spinal neural

circuits and improve functional recovery (2). Electrical stimulation delivered to dorsal spinal cord structures can increase the excitability of spinal locomotor networks and support activation of residual descending motor pathways.

Recent research suggests that targeted spinal cord stimulation, particularly when used alongside rehabilitation, may improve voluntary motor control and locomotor function in patients with chronic spinal cord injury (3–5). In parallel, emerging evidence suggests that epidural spinal cord stimulation may facilitate the reactivation of dormant motor and autonomic neural circuits, even in patients with long-standing and severe injury (6). Together, these findings support the concept that spinal neural networks retain a degree of functional plasticity and residual connectivity below the level of injury, even long after the initial insult.

Neurological and functional recovery in SCI is commonly evaluated using widely used clinical outcome measures. The American Spinal Injury Association Impairment Scale (AIS) is commonly used to classify neurological impairment, while the Spinal Cord Independence Measure (SCIM) is used to assess functional independence in daily activities (7,8). A change of approximately 10 points in the SCIM score is generally considered clinically meaningful (9).

Despite the increasing number of studies on epidural spinal cord stimulation, the majority of reported cases involve traumatic spinal cord injury. The application of this approach in individuals with chronic neurological deficits following spinal cord tumor surgery remains poorly documented. In this report, we present a patient with long-standing neurological impairment after thoracic spinal ependymoma surgery who demonstrated meaningful motor and functional improvement following epidural spinal cord stimulation more than two decades after the initial injury.

Case presentation

A 51-year-old male presented with chronic neurological deficits secondary to spinal cord tumor surgery performed in 2000. According to the available medical records, the lesion was consistent with a thoracic intramedullary ependymoma located between the T8 and T12 levels. Magnetic resonance imaging demonstrated postoperative changes with thoracic spinal cord atrophy and no evidence of tumor recurrence or active spinal cord compression (Fig. 1).

Following surgery, the patient developed persistent neurological impairment, including lower-extremity weakness and sensory deficits below the T10 level. Despite long-term self-directed exercise, he continued to experience substantial functional limitations and required an assistive device for ambulation.

Neurological examination revealed right-dominant lower-extremity weakness, as detailed in Table 1. Sensory examination demonstrated hypoesthesia below the T10 dermatome. Bowel and bladder continence were preserved at baseline. Sexual function was impaired.

EES implantation, intraoperative mapping, and stimulation protocol

Due to persistent functional limitations, epidural spinal cord stimulation was performed on October 23, 2024. EES implantation was performed through an L2 laminectomy. A 32-contact paddle lead connected to a WaveWriter neuromodulation system (Boston Scientific) was advanced epidurally and positioned over the T12-L1 levels under fluoroscopic guidance (Fig. 2). Final lead positioning was further guided by intraoperative functional mapping to obtain reproducible motor responses in clinically relevant lower-extremity muscle groups.

During intraoperative mapping, 2-Hz pulsatile stimulation was used to produce discrete contraction-relaxation responses that could be visually and clinically assessed. Particular attention was given to recruitment of the gluteal muscles, quadriceps, tibialis anterior, and distal toe flexor musculature. Gluteal and quadriceps responses were prioritized because of their contribution to pelvic stability, weight bearing, knee control, and walking, whereas tibialis anterior recruitment was used to assess the ability of stimulation to facilitate ankle dorsiflexion. Reproducible distal toe-flexion responses were also observed during mapping and were considered when evaluating distal and sacral-related motor recruitment. Contact configurations that produced selective and reproducible responses in these target muscle



Figure 1. Thoracic magnetic resonance imaging demonstrating postoperative spinal cord atrophy without evidence of tumor recurrence or active spinal cord compression.

groups while limiting unwanted activation of the contralateral or less-affected limb were preferentially selected for postoperative programming.

Following implantation, stimulation parameters were individualized according to the patient's residual voluntary motor function, functional goals, and responses observed during programming. Motor-oriented programs were predominantly delivered at 40 Hz, with an amplitude generally maintained at approximately 3-4 mA and a pulse width of approximately 300 μ s. Higher stimulation intensities or broader pulse widths produced less selective recruitment and unwanted contractions, particularly in the less-affected lower-extremity. Therefore, the parameters were kept within a range that provided useful motor facilitation while minimizing unintended muscle activation.

Because the patient retained voluntary activation of several lower-extremity muscle groups and did not exhibit clinically relevant spasticity, programming was progressively directed toward postural stability, balance, weight transfer, coordinated lower-extremity recruitment, and gait support, rather than simply eliciting stronger isolated muscle contractions. Separate task-specific programs were available for walking, exercise, sitting/postural control, bowel-bladder routines, and 2-Hz pulsatile stimulation for passive exercise.

Table 1. Baseline motor strength assessment before epidural spinal cord stimulation (MRC scale).

Muscle group	Left	Right
Plantar flexion	5/5	2/5
Dorsiflexion	4/5	2/5
Pelvic elevation (hip hike)	4/5	3+/5
Ankle inversion	3+/5	2/5
Ankle eversion	3+/5	1/5
Knee extension	5/5	2/5
Knee flexion	4/5	1/5
Hip flexion	4/5	1/5
Hip extension	4/5	1/5
Hip adduction	4/5	2/5
Hip abduction	4/5	1/5

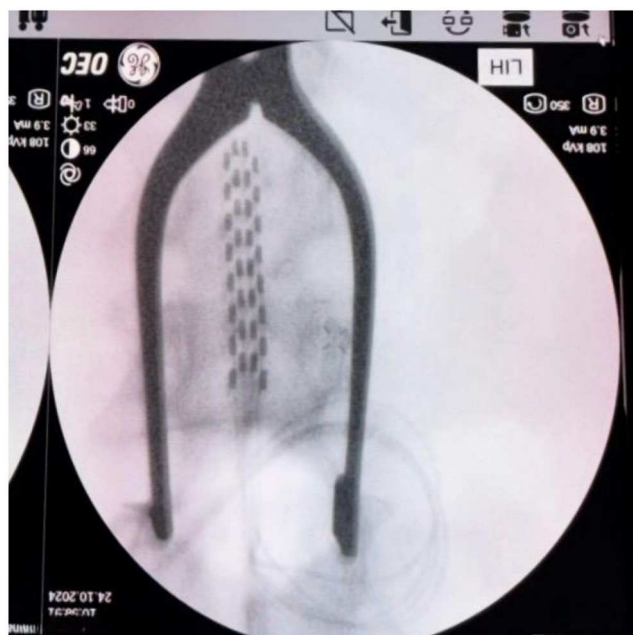


Figure 2. Fluoroscopic image showing epidural electrode placement.

Dedicated programs targeting sexual function were programmed at approximately 200-400 Hz. However, no sustained clinically meaningful improvement in sexual function was observed during follow-up. Bowel and bladder continence were already preserved before implantation; nevertheless, sphincter-related function showed a modest partial improvement during follow-up, with the SCIM III Respiration and Sphincter Management subdomain increasing from 36/40 at baseline to 38/40 at 6 months and remaining stable thereafter. Accordingly, this change is described as a partial improvement in sphincter-related function rather than recovery of continence.

Stimulation was activity-dependent rather than continuously delivered using a single program. During waking hours, the patient independently selected among predefined programs according to the intended activity. The stimulator was routinely switched off during sleep because the patient reported morning fatigue when stimulation remained active overnight.

Neurological and functional outcomes

During the five years before EES implantation, the patient maintained a regular self-directed exercise routine consisting of daily sit-to-stand training for approximately 10-15 min, stationary cycling for about 30 min, and walking sessions totaling approximately 45 min three times per week. However, preoperative ambulation required the use of a cane, and the patient needed to stop and rest approximately every 5-10 min because of limited walking endurance and gait impairment. No standardized preoperative walking test such as the 6MWT or 10MWT was available. He did not participate in a structured supervised rehabilitation program during this period. The same self-directed exercise routine was continued after EES implantation without the addition of formal rehabilitation.

Following EES implantation and subsequent programming, gait stability and walking endurance improved. The patient progressed from cane-assisted ambulation requiring rest approximately every 5-10 min to ambulation without a cane or other assistive device and without physical assistance from another person.

On postoperative day 10, ankle dorsiflexion strength improved from 2/5 to 4/5. Gait stability subsequently improved, and the patient progressed from cane-assisted ambulation to walking without an assistive device or physical assistance from another person. Motor strength assessment at the 12-month follow-up demonstrated persistent gains with stimulation OFF and additional facilitation with stimulation ON, as summarized in [Table 2](#). Bowel and bladder continence remained preserved throughout follow-up.

Table 2. Motor strength assessment at 12-month follow-up with stimulation OFF and ON (MRC scale).

Muscle group	Left (OFF)	Left (ON)	Right (OFF)	Right (ON)
Plantar flexion	5/5	5/5	2/5	4/5
Dorsiflexion	4/5	5/5	4/5	5/5
Pelvic elevation (hip hike)	4/5	5/5	3+/5	4/5
Ankle inversion	3+/5	5/5	2/5	2/5
Ankle eversion	3+/5	4/5	1/5	3/5
Knee extension	5/5	5/5	4/5	4+/5
Knee flexion	4/5	5/5	1/5	3/5
Hip flexion	4/5	5/5	1/5	3/5
Hip extension	4/5	4/5	1/5	2/5
Hip adduction	4/5	4/5	2/5	3/5
Hip abduction	4/5	4/5	1/5	3/5

Sexual dysfunction persisted without sustained clinically meaningful improvement during dedicated stimulation programs.

At baseline, the patient was classified as AIS C, with a Lower Extremity Motor Score (LEMS) of 18. He had chronic neurological deficits secondary to thoracic spinal cord injury following spinal endymoma surgery, with involvement extending from T8 to T12 and evidence of lower motor neuron/root involvement. Before EES implantation, he was capable of household ambulation only with an assistive device and was not independently ambulatory without support.

During follow-up after EES implantation, ambulatory function progressively improved from household ambulation requiring a cane to independent ambulation without a cane or other assistive device and without physical assistance from another person.

At follow-up, the patient was classified as AIS D, and this neurological classification remained unchanged between stimulation-OFF and stimulation-ON conditions. Thus, the AIS grade itself was not dependent on active stimulation. However, stimulation produced a clear augmentation of voluntary motor performance in selected lower-extremity muscle groups. This effect was particularly evident in the quadriceps and tibialis anterior. Ankle dorsiflexion showed a pronounced stimulation-dependent response, approaching near-normal strength with EES ON compared with the OFF condition. These findings suggest that the longitudinal change in neurological classification and the immediate facilitation of motor output during stimulation represent related but distinct observations.

At baseline, right ankle dorsiflexion and knee extension were markedly impaired, with muscle strength of approximately 2/5. By the latest follow-up, these gains were maintained even with stimulation switched OFF, with both muscle groups reaching approximately 4/5. Acute activation of EES produced an additional increase in motor output. This effect was particularly evident in the tibialis anterior, with ankle dorsiflexion increasing from 4/5 in the OFF condition to near-normal strength in the ON condition. Quadriceps strength similarly increased further during active stimulation. Importantly, the patient's AIS grade remained D under both OFF and ON conditions, indicating that the neurological classification at follow-up was not dependent on active stimulation.

Functional independence was measured with the Spinal Cord Independence Measure III (SCIM III). Subdomain analysis showed that the increase in total SCIM was driven predominantly by mobility. Self-care remained 20/20 throughout follow-up. Respiration and sphincter management increased modestly from 36/40 at baseline to 38/40 at 6 months and remained stable thereafter. Combined mobility increased from 28/40 at baseline to 32/40 at 3 months, 38/40 at 6 months, and 40/40 at both 9 and 12 months. Total SCIM III therefore increased from 84 at baseline to 88, 96, 98, and 98 at 3, 6, 9, and 12 months, respectively (Table 3; Fig. 3).

Table 3. Neurological classification and longitudinal SCIM III total and subdomain scores.

Time point	AIS grade	Self-care(0-20)	Respiration & sphincter management(0-40)	Mobility: room/toilet(0-10)	Mobility: indoors/outdoors(0-30)	Total mobility(0-40)	Total SCIM III(0-100)
Preoperative	C	20	36	10	18	28	84
3 months	D	20	36	10	22	32	88
6 months	D	20	38	10	28	38	96
9 months	D	20	38	10	30	40	98
12 months	D	20	38	10	30	40	98

Figure 3. Timeline of Neurological and Functional Outcomes After Epidural Spinal Cord Stimulation (EES)

Stimulation-associated motor and functional improvement after EES in chronic SCI secondary to spinal ependymoma

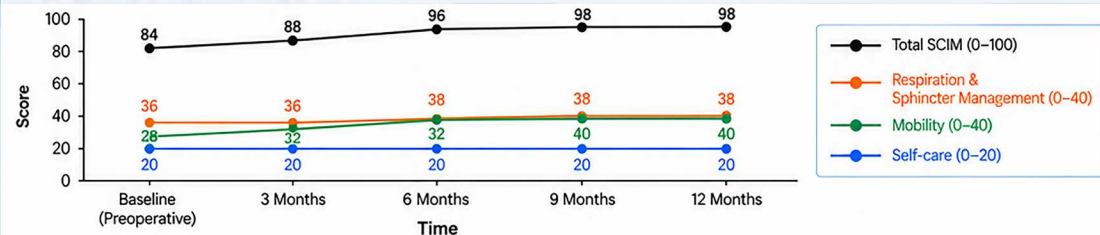


SCIM III Scores (0–100) and Subdomains

Measure	Baseline (Preoperative)	3 Months Postoperative	6 Months Postoperative	9 Months Postoperative	12 Months Postoperative
—●— Total SCIM (0–100)	84	88	96	98	98
—●— Self-care (0–20)	20	20	20	20	20
—●— Respiration & Sphincter Management (0–40)	36	36	38	38	38
—●— Mobility (0–40)	28	32	38	40	40

Improvements in total SCIM were primarily driven by mobility gains (28 → 40). Respiration & sphincter management improved modestly (36 → 38), consistent with partial improvement in sphincter-related function. Self-care remained unchanged (20/20) throughout follow-up.

SCIM III Scores and Subdomains Over Time



12-Month Motor Performance: Stimulation OFF vs ON (at Same Charge Density)

Muscle (MRC)	OFF	ON	Difference
Tibialis Anterior (R/L)	3 / 3	4 - / 4	+1 to +1
Quadriceps (R/L)	4 / 4	4+ / 5	+ to +1
Gluteus Maximus (R/L)	4 / 4	4+ / 4+	+ to +
Toe Flexors (R/L)	3 / 3	4 / 4	+1 to +1

Motor facilitation was observed in all tested muscle groups during active EES. AIS grade remained unchanged (AIS D) in both OFF and ON conditions.

Neurological Status	Baseline (Preoperative)	3 Months Postoperative	6 Months Postoperative	9 Months Postoperative	12 Months Postoperative
AIS Grade	C	D	D	D	D
Lower Extremity Motor Score (LEMS)	18	23	27	29	29

- Baseline AIS C with LEMS 18.
- Conversion to AIS D at 3 months and maintained through 12 months.
- LEMS improved from 18 to 29.
- AIS examination performed with stimulation OFF.



Autonomic Function

- Bowel and bladder continence were already preserved before implantation and remained unchanged.
- SCIM Respiration & Sphincter Management improved modestly from 36 to 38.
- This reflects partial improvement in sphincter-related functions rather than continence (e.g., ease/regularity of management).



Sexual Function

- Patient used sexual-function programs (200–400 Hz) without complications.
- No sustained, clinically meaningful improvement in erectile function was observed.
- No formal sexual-function scoring was performed.

EES: Epidural spinal cord stimulation; SCI: Spinal cord injury; SCIM III: Spinal Cord Independence Measure III; AIS: American Spinal Injury Association Impairment Scale; LEMS: Lower Extremity Motor Score; MRC: Medical Research Council.

Figure 3. Clinical timeline showing the patient's neurological and functional improvement.

Discussion

In recent years, epidural spinal cord stimulation has been increasingly used as a neuromodulation-based treatment for chronic spinal cord injury. Experimental and clinical evidence indicates that electrical stimulation delivered to the dorsal spinal cord can increase the excitability of spinal neural networks and support activation of locomotor circuits below the level of injury (6). Through modulation of spinal interneuronal pathways, epidural stimulation may enable residual supraspinal signals to activate motor neurons that would otherwise remain functionally silent after injury.

During the past decade, several clinical studies have demonstrated that targeted spinal cord stimulation combined with rehabilitation can improve voluntary motor control and locomotor function in individuals with chronic spinal cord injury (3–5). These observations challenge the traditional view that neurological improvement observed during stimulation is unlikely in the chronic phase of SCI and suggest that spinal neural circuits may retain functional plasticity even many years after the initial insult.

Although the majority of published reports focus on traumatic spinal cord injury, non-traumatic causes such as spinal cord tumors represent an important but less frequently investigated source of chronic neurological impairment. Ependymomas are the most common intramedullary spinal tumors in adults and are generally treated with surgical resection (1). Nevertheless, neurological deficits may persist following tumor removal due to prolonged spinal cord compression, tumor-related tissue injury, or surgical manipulation.

In the present case, the patient developed chronic spinal cord injury after thoracic spinal ependymoma surgery and continued to experience neurological deficits for approximately 24 years before undergoing neuromodulation therapy. Such a long interval after injury would typically be considered unfavorable for neurological improvement. Despite this prolonged duration, epidural spinal cord stimulation was associated with noticeable improvements in voluntary motor function, gait stability, and overall functional independence.

Bowel and bladder continence were preserved before implantation. During follow-up, the SCIM III Respiration and Sphincter Management subdomain increased modestly from 36/40 to 38/40, indicating a partial improvement in sphincter-related function despite preserved baseline continence. We therefore do not characterize this finding as recovery from urinary or fecal incontinence. Sexual function was impaired at baseline. Although dedicated stimulation programs at approximately 200–400 Hz were tested, no sustained clinically meaningful improvement was observed. Sexual function was not assessed using a validated instrument, and no objective recovery of erectile function is claimed.

Objective changes in neurological and functional status were assessed using standardized outcome measures. The patient's neurological classification changed from AIS C at baseline to AIS D during follow-up. Importantly, AIS D was maintained in both stimulation-OFF and stimulation-ON conditions at the latest assessment, whereas active stimulation produced additional facilitation of selected lower-extremity muscle groups. SCIM III increased from 84 to 98, with subdomain analysis demonstrating that the functional gain was predominantly attributable to improved mobility (Table 3).

The 14-point increase in total SCIM III exceeded the approximately 10-point change generally considered clinically meaningful in SCI. The stability of self-care scores and the predominant increase in mobility further support that the observed functional change was principally locomotor rather than an improvement in continence.

Although the previous T8–T12 tumor resection and chronic neurological injury raised the possibility of mixed upper motor neuron and segmental lower motor neuron/root involvement, reproducible motor responses elicited during low-frequency intraoperative mapping indicated preserved recruitability of the targeted lumbosacral sensorimotor pathways. These findings supported proceeding with task-specific EES programming, although they do not constitute a formal electrophysiological distinction between upper and lower motor neuron pathology.

Another important aspect of this case is that the patient did not undergo intensive supervised rehabilitation during the study period. Because his long-standing self-directed exercise routine was maintained without the introduction of a new structured rehabilitation program after implantation, the temporal association with EES and the observed ON/OFF differences suggest a contribution of stimulation to the functional changes. However, the independent effects of stimulation and ongoing physical activity cannot be fully separated in a single-case design.

No standardized preoperative 6-minute walk test, 10-meter walk test, or Walking Index for spinal cord injury II score was available; therefore, gait speed and walking distance could not be quantified retrospectively. Further studies using standardized neurological, gait, autonomic, and patient-reported outcome measures are needed to clarify the role of EES in patients with spinal cord injury secondary to spinal tumors.

Conclusion

Epidural spinal cord stimulation may represent a promising therapeutic option for selected patients with chronic neurological deficits following spinal ependymoma surgery. In this case, clinically meaningful motor and functional improvements were observed more than two decades after the initial injury. Longitudinal gains were retained with stimulation OFF, while active stimulation provided additional facilitation of selected lower-extremity muscles. Further studies using standardized neurological, gait, and autonomic outcome measures are needed to define the contribution of EES in this population.

Disclaimer statements

Contributors A.C.B. conceived and designed the study and performed the surgical procedure. A.C.B. and A.D.Y. analyzed and interpreted the data. S.S. and E.E. conducted neuromodulation programming and collected clinical data. E.B. performed neurological evaluation and follow-up. E.G. contributed to data interpretation and critical revision of the manuscript. A.C.B. drafted the manuscript. A.D.Y. and E.G. critically revised the manuscript. L.S. contributed to data interpretation and critical revision of the manuscript. E.E.D. revision. G.A. revision. G.M. revision. Aslihan Cevik Baran: conceptualization, methodology, surgical intervention, investigation, writing – original draft, supervision. Edip Gonullu: clinical evaluation, data interpretation, writing – review and editing. Ece Balkuv: data curation, functional outcome assessment, data interpretation, writing – review and editing. Arzu Dinc Yavas: clinical and functional evaluation, data interpretation, writing – review and editing. Seyma Sarioglu and Emir Eker: physiotherapy-related assessment, stimulation programming support, data collection, writing – review and editing. Luay Serifoglu: neurological evaluation, data interpretation, writing – review and editing. Elif Elcin Dereli: evaluation and interpretation of rehabilitation and functional outcome data, including longitudinal SCIM III data, writing – review and editing. Gorkem Acar: data organization, quantitative verification, tables and figures, writing – review and editing. Georgios K. Matis: neuromodulation expertise, interpretation of the stimulation strategy and clinical findings, literature review, critical revision and senior scientific input. All authors reviewed and approved the final manuscript.

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Declaration of interest

None.

Conflicts of interest

Authors have no conflict of interests to declare.

Ethics approval and consent to participate

Ethical approval was obtained from the institutional review board. Written informed consent was obtained from the patient.

Ethical approval for the research use and reporting of the clinical data was obtained from the Istanbul Bilgi University Ethics Committee (Project No. 2025-20162-179; date of evaluation: August 29, 2025). The application was reviewed and found eligible without requiring revision.

Consent for publication

Written informed consent was obtained from the patient for publication of this case report and accompanying images.

Data availability statement

Data supporting the findings of this case report are available from the corresponding author on reasonable request, subject to patient privacy and consent restrictions.

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