Clinical and Neurophysiologic Assessment of Strength and Spasticity During Intrathecal Baclofen Titration in Incomplete Spinal Cord Injury: Single-Subject Design

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Abstract

Background/Objective: Spasticity after spinal cord injury (SCI) is commonly managed with oral and intrathecal baclofen (ITB), with less attention to the effects on voluntary motor control. Studies combining clinical and neurophysiologic assessments during dose optimization are rare. Study aims (a) systematically evaluate effects of varied doses of oral and ITB on clinical and neurophysiologic measures of strength and spasticity and (b) relate clinical and neurophysiologic findings.

Methods: A 41-year-old man with an incomplete T11-ASIA D SCI was studied during ITB titration. Spasticity and strength in the lower extremities were assessed clinically and neurophysiologically at 5 different daily dosages of baclofen: (a) 80 mg oral, (b) 80 mg oral/50 µg ITB, (c) 80 mg oral/125 µg ITB, (d) 30 mg oral/125 µg ITB, and (e) 125 µg ITB only.

Results: A dose-dependent change in the Ashworth score and lower limb motor score was observed during titration of oral and ITB. Whereas the Hoffman (H)-reflex was abolished after the introduction of ITB, the flexion withdrawal reflex approximated a dose-dependent pattern. Changes in the motor score and EMG during voluntary muscle activation were proportionally smaller than the corresponding changes in clinical and neurophysiologic measures of spasticity. Neurophysiologic assessment largely paralleled clinical findings.

Conclusions: This single-subject study shows that the control of spasticity can be achieved without detrimental effects on strength in incomplete SCI and suggests the need for including strength testing in comprehensive clinical assessment of spasticity. The study shows convergent validity between clinical and neurophysiologic assessments during ITB dose titration. Adding neurophysiologic assessment to clinical assessment may provide objectivity and sensitivity and facilitate decision-making during ITB titration.

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INTRODUCTION

Spasticity is a multidimensional and challenging problem after spinal cord injury (SCI) in humans (1). It is classically defined as a motor disorder characterized by a velocity-dependent increase in tonic stretch reflex with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor

neuron syndrome (2). Other components of spasticity include clonus, involuntary muscle contractions or spasms, and muscle co-contraction. Each component, independently or combined, can decrease range of motion, impair voluntary movements, provoke pain, and result in a loss of function in activities of daily living (3,4).

Oral medications, such as baclofen, diazepam, and tizanidine, have been used to manage spasticity, but they often are accompanied by undesired side effects such as drowsiness, dizziness, hallucinations, and lethargy (5,6). As an alternative, intrathecal baclofen (ITB) has been delivered directly into the cerebrospinal fluid surrounding the spinal cord by means of a catheter connected to a

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battery-powered pump implanted in the abdominal wall. ITB permits application of much smaller doses because the medication is delivered near the site of its action, thus limiting the side effects associated with high doses of oral medication. As recently reviewed (7,8), there exists extensive clinical experience with this form of treatment for pain and spasticity of spinal and supraspinal origin both in children and adults.

In daily practice, the effectiveness of ITB administration on spastic hypertonia after SCI is based on clinical assessment. Most often, resistance to passive stretch is evaluated using the (Modified) Ashworth scale (9,10), a measure reflecting passive, intrinsic, and reflex-mediated stiffness (11,12). Some investigators have also used clinical ratings of spasms (13,14) or the Babinski response (15). Neurophysiologic techniques for assessing the spinal cord response to ITB after SCI have less often been used. Among these, Hoffman (H)-reflex, an electrical correlate of the tendon tap, has most commonly been used during the screening bolus trial and dose titration after pump implant (15–18). In addition, mechanically or electrically evoked withdrawal flexor reflex (19), an equivalent of the Babinski response, has occasionally been recorded and quantified (14,17,20). Although these neurophysiologic techniques seem useful, their clinical use has been uncertain.

Clinical studies concurrently evaluating the effects of ITB on spasticity, strength, and voluntary muscle activation are lacking (21). Strength testing has largely been ignored because the main candidates for ITB implants have been subjects with either complete SCI or incomplete SCI with only traces of voluntary movements, in whom ITB primarily targets spasticity that interferes with self-care or transfers. For a subset of patients who rely on residual motor control for functional mobility such as walking, it is imperative to determine whether a fine balance between spasticity and strength can be achieved. Neurophysiologic assessment of spasticity and voluntary muscle activation during ITB administration has sporadically been used but rarely compared side-to-side to clinical findings (22). Neurophysiologic evaluation has indeed been suggested as potentially beneficial for monitoring and attaining a balance between motor performance and spasticity after ITB administration (23).

The purpose of this study was to systematically evaluate the effects of varying doses of oral and ITB on clinical and neurophysiologic measures of strength and spasticity in a patient with an incomplete SCI. Our second goal was to assess the relationship between neurophysiologic and clinical findings to determine their clinical usefulness. More specifically, we aimed to assess the value of concurrent clinical and neurophysiologic evaluations of strength and spasticity during ITB titration as a way of achieving optimal therapeutic outcomes in incomplete SCI.

METHODS

Subject

The study participant was a 41-year-old man who had been injured 8 years previously in a motor vehicle crash. He agreed to participate in the study and signed the consent form approved by the hospital's Institutional Review Board for Human Research. At the time of this study, his injury was T11 ASIA Impairment Scale D. He previously ambulated with 2 single-point canes, but had been nonambulatory for the 9 months before ITB placement because of severe lower limb spasticity and pain. The patient was admitted to our facility for an ITB bolus trial through lumbar puncture, which resulted in a favorable reduction in spasticity and decreased pain. He subsequently underwent the ITB pump implantation and dose titration.

Design

We used a longitudinal single-subject design during an iterative ITB dose titration consisting of ITB escalation and weaning off of the oral baclofen. The dosage adjustment was carried out by a physician not taking part in this study. Clinical and neurophysiologic evaluations were performed by the same examiners on multiple sessions blinded for the dosage changes. Assessment was performed over a 3-week period on 5 different days at the following oral/ITB dosages: 80 mg of oral baclofen at baseline (80/0), 80 mg oral/50 µg ITB on day 3 postimplant (80/50), 80 mg oral/125 µg ITB on day 5 postimplant (80/125), 30 mg oral/125 µg ITB on day 8 postimplant (30/125), and 125 µg ITB only on day 19 postimplant (0/125). Clinical evaluation was performed at each titration level. Neurophysiologic recording was not done on day 3 (80/50) because of some postoperative discomfort. The final testing was performed on an outpatient basis because the patient was discharged several days after pump implantation. Data were analyzed by the investigator who designed the study protocol but did not participate in data collection.

Clinical Evaluation

Spasticity. Muscle hypertonia was assessed using a standard Ashworth scale (9) (range, 1–5) for 6 lower extremity muscle groups (hip flexors, hip extensors, hip adductors, knee flexors, knee extensors, and ankle plantar flexors). In addition, a spasm frequency scale (0–4) and a spasm severity scale (1–3) were used (1,24). Both scales were administered as self-reports at each dosage referring to the 2 sides combined.

Strength. Strength was assessed based on the motor score section of the International Standards for Neurological and Functional Classification of Spinal Cord Injury (ASIA standards) (25) for the following key muscles: hip flexors, knee extensors, ankle dorsiflexors, toe extensors, and ankle plantar flexors. In addition, hip extensors, knee flexors, and hip abductors were also

assessed using the same 0 to 5 rating scale in standardized test positions.

Neurophysiologic Evaluation

An EMG was recorded using surface Ag-AgCl electrodes (diameter, 0.8 cm) centered 3 cm apart over the muscle bellies. Before electrode placement, the skin was slightly abraded to reduce skin impedance (<5 kOhm). Electrode locations were identified with an indwelling marker to ensure reproducible placement of the electrodes across different days. Data were recorded using commercially available EMG apparatus (Viking IVP; Nicolet Biomedical, Madison, WI).

H-Reflex. The study participant was resting in the supine position on the examination bed. A pair of surface electrodes was placed over the belly of soleus muscle for bipolar recording. The reflex was evoked by electrical stimulation of the tibial nerve (1 ms in duration) with a round cathode (1 cm in diameter) placed in the popliteal fossa and a rectangular anode (4×5 cm) placed above the knee cap. The stimulus was delivered every 10 seconds. Current was increased in small increments (0.4–0.8 mA) until the maximum H-reflex and maximum M-wave amplitudes were obtained (1 stimulus at each stimulus level). The recruitment curve was therefore mapped with a particular attention to the ascending limb and peak of the H-reflex.

Plantar Withdrawal Reflex. The plantar withdrawal reflex was evoked by mechanical stimulation of the sole of the foot by moving a blunt probe along the lateral border of the foot and across the metatarsal bones (17). The study participant was instructed to relax to the best of his abilities and not to resist the evoked motion, if any. EMG was recorded over a 5-second window from ipsilateral hamstrings (H), quadriceps (Q), tibialis anterior (TA), and triceps surae (TS). The test was repeated 3 times on each side at random intervals greater than 30 seconds to avoid habituation.

Maximal Voluntary Ankle Dorsiflexion. The study participant was asked to perform 3 trials of maximal isometric ankle dorsiflexion in a supine position (17). Only the left side was tested because it produced reproducible contractions not accompanied by spasms. The examiner provided a resistance with the ankle held at 90 degrees for 5 seconds. Approximately 1 minute of rest was given between each contraction. The EMG was recorded over a 10-second window from the ipsilateral H, Q, TA, and TS. In addition, maximum M-wave was recorded from the TA muscle by stimulating the peroneal nerve behind the fibular head, which permitted normalizing voluntary EMG area to the maximal M-wave area.

Data Analysis

Individual muscle Ashworth scores were summed into left, right, and total Ashworth Score (AS). Similarly, individual strength scores were summarized into left,

Table 1. Summary of Ashworth Scores in 8 Major Muscle Groups Across the Hip, Knee, and Ankle Joints on Each Side at Various Oral/ITB Dosages

	Oral (mg)/ITB (μ g/d) Dosage				
Ashworth Score	80/0	80/50	80/125	30/125	0/125
Left sum	12	9	8	8	10
Right sum	12	10	8	10	7
Total sum	24	19	16	18	17

Data are expressed as a sum (left, right, and total) and mean $\pm$ SD (total).

right, and total Muscle Score (MS). Means for AS and MS were also calculated for the 2 legs combined. Nonparametric repeated-measures ANOVA (Friedman test) was used to examine the main effect of baclofen dosage on AS and MS in the recorded muscles, respectively. If ANOVA was significant ($P < 0.05$), a post hoc Dunn multiple comparison test was applied to compare differences between various baclofen dosages. Spasm frequency and spasm severity scores were reported for each dosage.

For the soleus H-reflex, peak-to-peak amplitude of the maximum H-reflex was divided by the maximum M-wave to derive the H/M ratio (H/M) (26). For the plantar withdrawal reflex, the EMG area (μ V $\times$ ms) of the evoked response was calculated for each muscle and divided by the respective response duration. The resulting mean voltage (μ V) was averaged across the 3 trials for each muscle and grand-averaged across multiple muscles on each side. For the maximal voluntary ankle dorsiflexion, EMG area (μ V $\times$ ms) corresponding to the middle 1 second of voluntary contraction was calculated for each muscle, divided by the response duration, and averaged across the 3 trials. The mean EMG (μ V) in the target TA muscle was compared to the sum of mean EMG in the coactivated ipsilateral quadriceps, hamstring, and triceps surae muscles. In addition, raw EMG in the TA was also normalized to the M-wave area (baseline-to-negative peak) to eliminate possible confounding effect of electrode placement across different recording sessions. GraphPad Prism 3.0 software (GraphPad, San Diego, CA) was used for statistical analysis.

RESULTS

Clinical Findings

Spasticity. Changes in left, right, and total AS are presented in Table 1. The highest AS was obtained at baseline (80/0) when 6 of 16 muscles scored 2 or 3. Conversely, the lowest AS was recorded at the highest combined oral and ITB dosage (80/125) when all muscles scored 1. AS somewhat increased as the oral baclofen was progressively withdrawn, thereby creating a “U” shape across all dosages. Nonparametric ANOVA yielded a significant main effect of baclofen dose on AS ($P < 0.01$),

Table 2. Summary of Muscle Scores Based on the ASIA Standards for the 5 ASIA Key Muscles Plus Hip Extensors, Knee Flexors, and Hip Abductors at Various Oral/ITB Dosages

	Oral (mg)/ITB (μg/d) Dosage				
Muscle Score	80/0	80/50	80/125	30/125	0/125
Left sum	29	15	20	18	25
Right sum	34	26	26	31	32
Total sum	63	41	46	49	57
Total mean ± SD	3.9 ± 1.1	2.6 ± 1.4	2.9 ± 1.3	3.1 ± 1.5	3.6 ± 1.2

Data are expressed as a sum across multiple muscles (left, right, and total) and mean ± SD (total).

indicating the overall significant change across multiple evaluation points. Post hoc analysis adjusted for multiple comparisons, however, did not show significant differences between any 2 given dosages.

At baseline (80/0), the spasm frequency score was the highest possible (4), and no change was reported at 80/50. Spasm frequency was scored 2 for both the 80/125 and 30/125 dosages, decreasing to a lowest possible (1) when oral medication was completely withdrawn (0/125). Spasm severity was scored 3, the highest possible, at baseline (80/0) and at 80/50. It was rated the lowest (1) across the final 3 dosages (80/125, 30/125, and 0/125).

Strength. Changes in muscle strength for left and right leg and the 2 sides combined are summarized in Table 2. The highest MS was recorded at baseline (range, 2–5), when 13 of 16 muscles scored 4 or 5. Minimum MS was seen on day 3 at 80/125 (mean, 2.9), the highest combined dosage of oral and ITB, when 8 of 16 muscles

scored 4 or higher. Gradual recovery in total MS was seen as the oral medication was withdrawn during the remaining 2 test days (means, 3.1 and 3.6, respectively). Nonparametric ANOVA showed a significant effect of baclofen dose on MS ($P < 0.001$) across the 5 evaluation points. Post hoc analysis showed significant differences in MS between 80/0 and 80/50 ($P < 0.001$), between 80/0 and 80/125 ($P < 0.05$), and between 80/50 and 0/125 ($P < 0.05$). Therefore, administration of ITB reduced the strength, which evidently recovered as the study participant was weaned off of the oral baclofen.

Figure 1 depicts the above described findings for strength and spasticity where relative change in total AS is plotted against the relative change in total MS across various dosages. Introducing ITB decreased both AS and MS from their baseline values (80/0). MS increased for 16 points between the lowest and the final point, whereas AS increased only for 2 points. Thus, a titration of oral and ITB resulted in noticeable recovery in strength with only a minor increase in spasticity.

Neurophysiologic Findings

H/M Ratio. The baseline soleus H/M ratio (80/0) measured 60% on the left and 54% on the right side. Adding ITB significantly abolished the H/M ratio to 2%, 2%, and 4% on the left and 3%, 1%, and 1% on the right at 80/125, 30/125, and 0/125, respectively.

Plantar Withdrawal Reflex. The largest baseline responses on average were recorded in the left hamstrings ($49 \pm 11 \mu\text{V}$) and right TA ($59 \pm 10 \mu\text{V}$). An example of the response in the ipsilateral muscles to left side plantar stimulation is shown in Figure 2. At baseline, the response was immediate, long-lasting, and high in amplitude. It significantly diminished in amplitude and duration at the highest combined amount of baclofen (80/125). Mean EMG amplitudes across multiple sessions are presented in Figure 3 for each leg, which shows that introducing ITB and withdrawing oral baclofen resulted in a substantial decrease of mean EMG followed by a partial increase. When averaged across all muscles and the 2 sides, the amplitude of plantar withdrawal reflex was 11%, 9%, and 37% of baseline at 80/125, 30/125, and 0/125, respectively.

Figure 1. Percent change in the total Ashworth Score (y-axis) is plotted against the percent change in total Muscle Score (x-axis) relative to baseline (0/80, arrow) for various oral/ITB doses. Note a remarkable change in both strength and hypertonia with introduction of ITB. After withdrawal of oral medication, an improvement in strength is greater than a rebound in hypertonia.

Figure 2. Responses to plantar stimulation recorded in 4 muscles simultaneously at 80 mg of oral baclofen only (0/80, left panel) and after adding 125 $\mu g/d$ of ITB (125/80, right panel). Note a reduction in EMG on the right panel.

Maximal Voluntary Ankle Dorsiflexion. Baclofen titration resulted in a dose-dependent reduction of EMG amplitude in the TA muscle acting as an agonist during maximal voluntary contraction of the ankle dorsiflexors. The mean EMG in the left TA was 30, 5, 8, and 17 μV for the 4 respective baclofen dosages (Figure 4). The same “U” shape relationship was preserved when the EMG in the TA was normalized to its M-wave amplitude (37, 7, 10, and 27 arbitrary units). Figure 4 also shows a noticeable level of co-contraction in the quadriceps, hamstrings, and triceps surae muscles. As with the TA, the degree of co-contraction remarkably decreased after adding ITB at 150 $\mu g/d$. An initial recovery of EMG in the TA, because of a partial withdrawal of oral baclofen (30/125), was accompanied by an increase of EMG in the coactivated muscles that exceeded the baseline level. Final withdrawal of oral baclofen reversed the modulation of EMG in the agonist and coactivated muscles so that the TA EMG further recovered, whereas the amount of coactivation decreased, although it remained above the baseline.

DISCUSSION

The main result of this single-subject study is a dose-dependent change in spasticity and strength during titration of oral and ITB shown in parallel by clinical and neurophysiologic assessments. More specifically, the following results were observed: (a) decrease in clinical indices of spasticity at the end of titration seems larger than the corresponding decrease in voluntary muscle strength; (b) neurophysiologic assessment of spasticity shows a profound reduction in monosynaptic reflexes and dose-dependent modulation in polysynaptic reflexes; and (c) voluntary isometric activation of the target muscle and accompanied co-contraction in remote ipsilateral muscles are also modified in a dose-dependent

Figure 3. EMG amplitudes (mean $\pm$ SD) during elicitation of plantar withdrawal response in left and right leg muscles (average of 3 trials). Note dose-dependent changes on both sides.

manner, first in parallel, and then in opposite directions at the maximum overall dosage, with normalization after weaning off of oral baclofen. Overall, neurophysiologic findings corroborated clinical changes in strength and spasticity.

Administration of ITB significantly affected several clinical features of spasticity, namely hypertonia, spasm frequency, and spasm severity. These findings are consistent with existing reports showing a significant reduction in resistance to passive stretch, as well as frequency and severity of involuntary movements in spasticity of spinal origin, such as with SCI and multiple sclerosis (13,15,27–30). Systematic dose-response stud-

Figure 4. EMG amplitudes (mean $\pm$ SD) in the target tibialis anterior muscle and co-activated quadriceps, hamstrings, and triceps surae muscles during maximal voluntary activation of the left ankle dorsiflexors. Note dose-dependent changes in the target and co-activated muscles that were at first similar and then reciprocal with a withdrawal of oral baclofen.

ies have not been previously carried out, however, and changes in spasticity have been reported over time rather than in terms of a dose. We observed a clear dose-dependent change in spastic hypertonia over the range of examined doses. Self-reported changes in frequency and severity of spasms were also evident but less sensitive to minor adjustments in the overall baclofen dosage. For example, adding 50 $\mu\text{g}/\text{d}$ of ITB, or completely withdrawing oral baclofen, had virtually no effect on either measure. This could be attributed, in part, to a low sensitivity of spasm frequency and spasm severity scales at either end of the spectrum and to a subjective nature of self-reported scales.

Adding 150 $\mu\text{g}/\text{d}$ of ITB to 80 mg/d of oral baclofen in our study significantly decreased excitability within the mono- and polysynaptic reflex pathways. Subsequent withdrawal of oral baclofen, however, left the near-absent H-reflex virtually unaffected, in contrast to a partial recovery of the plantar withdrawal reflex. This indicates that the changes in the polysynaptic reflex pathway are dose dependent and evident over a larger range of baclofen doses than in the monosynaptic reflex pathway. Administration of ITB bolus during the screening trial decreases H-reflex amplitude in a time- and dose-dependent manner, eventually leading to its complete disappearance (15–17). The results of this study are in agreement with our recent report (31) in acquired brain injury, which showed that the H-reflex sharply decreases over the initial 150 $\mu\text{g}/\text{d}$ of continuous ITB and thereafter disappears or reaches a low amplitude plateau. Thus, the reflex pathway mediating H-reflex is the most susceptible to ITB and remains barely excitable once critical threshold is reached. Because of such a high sensitivity, the H-reflex has been advocated as a mean of monitoring the titration, effectiveness, and problems with ITB administration (18,31–34).

Our findings are also in agreement with previously reported changes in the polysynaptic flexion withdrawal reflex during bolus or continuous ITB administration (14,17,20). ITB increases reflex threshold and decreases both the amplitude and duration of reflex response (Figure 2). Changes in the flexion withdrawal reflex in this study largely mirrored self-reported changes in spasm frequency and severity. This is reassuring as increased flexion reflex threshold is expected to reduce the number of spasms, whereas decreased reflex amplitude and duration lessen their severity. Such concordant changes, however, do not imply the existence of strict correlation between the clinical and neurophysiologic measures of spasms. Indeed, a poor correlation between spasm scores and flexion reflex parameters has been reported before and during continuous ITB administration (20). The likely reason is a low sensitivity of ordinal clinical scales compared with quantifiable neurophysiologic measures.

We also observed a dose-dependent change in clinical measures of lower limb strength. The pattern of change in strength across various dosages, however, was

somewhat skewed compared with changes in hypertonia. In other words, after reaching their respective lowest point, complete withdrawal of oral baclofen resulted in a large recovery of strength in contrast to a minor rebound in hypertonia. At that point, the strength recovered to about 90% of baseline, whereas the hypertonia remained noticeably decreased (70% of baseline). Although different grading properties of the 2 ordinal scales have to be acknowledged, our findings suggest that differential modulation of strength and hypertonia can be detected by clinical evaluation and used during ITB dose optimization. Achieving a fine balance between changes in strength and hypertonia is particularly important for subjects with variably preserved voluntary motor control. As in a case of a locked-in patient, careful ITB titration may unmask even subtle motor abilities associated with a reduction in hypertonia (35). Our results also corroborate sporadic reports of subjective complaints of muscle weakness with oral or ITB baclofen that may (22) or may not be detected by formal strength testing (14,36). As recently reviewed (21), strength decreases may be temporary but could also be disabling and require reducing the dosage or completely discontinuing ITB administration. Our study thus showed that clinical strength testing should be considered a critical adjunct to comprehensive spasticity assessment and ITB management.

Neurophysiologic findings of voluntary muscle activation largely followed the results of clinical strength testing. After introducing ITB at 150 $\mu\text{g}/\text{d}$, the EMG in both the agonist TA muscle and the co-contracted ipsilateral muscles decreased to the lowest point across all dosages. This coincided with the lowest level of spasticity, detected both by clinical and neurophysiologic evaluations, which implies markedly reduced spinal excitability at the highest combined dose of baclofen. The decrease in voluntary muscle activation with higher doses of baclofen can be explained by decreased spinal motor neuron excitability (16,37), as well as reduction in afferent input that assists with sustaining a prolonged contraction (38). Initial reduction in oral baclofen led to a limited recovery of agonist EMG but increased coactivation well above baseline (Figure 4). After withdrawal of oral baclofen, voluntary EMG in the agonist further recovered and the coactivation decreased. Such an inverse modulation of activity in the agonist and coactivated muscles is typical of variably impaired motor control in upper and lower limbs after central nervous system lesion (39,40). Thus, the described pattern of change in the voluntary muscle activation suggests that the motor control at the end of titration remained impaired in comparison to the baseline despite achieving better spasticity control, which also follows clinical findings. The overall decrease in EMG during ITB titration reported here is in agreement with a case report describing the effects of a comparable dose of ITB in a child with spastic diplegia tested in a similar manner (22).

A higher degree of ipsilateral muscle co-contraction in our patient, however, is in contrast to the reported normalization of agonist-antagonist coactivation during movement after a single ITB bolus in children with cerebral palsy (41). The reasons might be the difference in testing procedures, less than optimal ITB dose in our patient, and spasticity of different origin.

The main limitation of this study is inherent to its single-subject design; thus, our results must be validated among a larger number of subjects with chronic incomplete SCI before reaching any firm conclusions. However, the single-subject design is becoming an increasingly recognized tool in rehabilitation research. It permits a systematic manipulation of an independent variable to examine its effect on a dependent variable (42). As such, it provides a quasi-experimental approach to studying causal relationships (43), which evidently is of value when approaching a complex clinical phenomenon such as spasticity.

CONCLUSION

In summary, our results indicated that in this person with an incomplete SCI, baclofen decreased spasticity by depression of multiple reflex pathways but also reduced excitability of neural structures underlying voluntary motor tasks, thereby altering muscle activation patterns. Neurophysiologic assessment provided objectivity, enhanced sensitivity, and independently confirmed the results of clinical evaluation of spasticity and motor performance during ITB titration. We also reaffirmed that various components of the upper motor neuron syndrome, such as hypertonia, hyperreflexia, spasms, weakness, and co-contraction, may be differentially modulated with antispasticity medication. Thus, therapeutic intervention after upper motor neuron lesion should optimize motor control by finely tuning its various components for achieving desired clinical goals. For individuals who rely on residual motor control for essential functional activities, spasticity reduction should be accompanied by the goal of maximizing available strength so that functional capacity is maintained. The prescription of ITB as an antispasticity medication should incorporate interdisciplinary team evaluation and include objective and sensitive outcomes spanning ITB screening trial, dose titration, and follow-up as the patient returns to the community. The team may consider combining clinical and neurophysiologic assessments into comprehensive spasticity evaluation and management.

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