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Effect of selective dorsal rhizotomy on bladder dysfunction in children with spastic cerebral palsy

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This study investigated the prevalence and severity of lower urinary tract symptoms (LUTS) in children with spastic cerebral palsy (SCP) and evaluated the effect of selective dorsal rhizotomy (SDR) in alleviating these symptoms. The study also explored the correlation between postoperative LUTS improvement and intraoperative electrophysiological findings. Prospective data were collected from a consecutive cohort of 247 children with SCP who underwent SDR and were retrospectively analyzed. Pre- and post-operative assessments included muscle tone, motor function, LUTS and intraoperative electrophysiology data were analyzed. Preoperatively, 94 patients (38.1%) had LUTS, and the severity of LUTS negatively correlated with motor function (R=-0.32, $P < 0.0001$). After SDR, muscle tone decreased, motor function improved ($P < 0.0001$), and LUTS resolved in 49/94 patients (52.1%). LUTS improvement correlated with a higher proportion of sensory nerves evoking anal sphincter EMG > 20μV. SDR effectively reduces spasticity, improves motor function, and alleviates LUTS in most children with SCP. Intraoperative neurophysiology may predict improvements, warranting further research.

Keywords Selective dorsal rhizotomy, Spastic cerebral palsy, Lower urinary tract symptoms, Intraoperative neurophysiological monitoring, Bladder dysfunction

Cerebral palsy refers to a group of motor function impairment syndromes caused by non-progressive damage to the brain during infancy or early childhood, and spastic cerebral palsy (SCP) is the most common type of cerebral palsy[1]. Children with SCP typically experience not only limb spasticity but also bladder dysfunction, which adds a dual burden of psychological and physiological challenges to both the affected children and their families[2].

Selective dorsal rhizotomy (SDR) is a neurosurgical procedure utilized to reduce spasticity, proving highly effective in treating children with SCP[3]. By attenuating sensory input from Iα fibers, SDR effectively reduces lower limb muscle tone in children with SCP, thereby enhancing their motor function[4]. Beyond treating spasticity in lower limbs, SDR has demonstrated promising outcomes in improving bladder function among children with SCP[5,6]. It is documented that SDR has been associated with improvements in urgency, frequency, urinary incontinence, and bladder capacity in this population. Overall, SDR emerged as a transformative intervention, markedly ameliorating lower urinary tract dysfunction in children with SCP and thereby enhancing their quality of life, particularly in terms of urinary control. However, the underlying mechanisms remain incompletely understood.

Intraoperative electrophysiological monitoring plays a pivotal role in assessing nerve function during SDR[7–9]. By closely monitoring the response of nerve roots to electrical stimulation, valuable insights into nerve function can be gleaned, which not only guides the SDR procedure but also holds potential for predicting postoperative changes in muscle tone[10]. To achieve a comprehensive understanding of the relationship between SDR and lower urinary tract symptoms (LUTS), this study retrospectively analyzed prospectively collected data from a consecutive cohort of children with SCP who underwent SDR. The specific research objectives were as follows: (1) Investigate the prevalence of LUTS in children with SCP; (2) Determine the efficacy of SDR in ameliorating

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LUTS in children with SCP; (3) Explore the correlation between postoperative improvement in LUTS and intraoperative electrophysiological data.

Methods and materials

Research population and data collection

Patients included in this study were consecutive cases diagnosed with SCP who were admitted to the Shanghai Children's Hospital from December 2018 to June 2023. This study collected clinical data from enrolled children. The main clinical data collected include: (1) General information about the children, such as gender, age, etc.; (2) Disease-related information, such as topographical type of SCP, affected limb sides, lower limb muscle tone, motor function, past treatment history, etc.; (3) Daily urinary habits, LUTS, and bowel movements, including daytime urinary incontinence, presence of nocturnal enuresis, urgency, frequency, etc.; (4) Intraoperative electrophysiological data monitored during SDR.

Inclusion/exclusion criteria

Inclusion criteria

① Diagnosed with SCP according to diagnostic criteria; ② Age between 4 and 18 years old; ③ Underwent SDR surgery; ④ Complete clinical data available; ⑤ Informed consent obtained from the children and their families.

Exclusion criteria

① Children with coexisting congenital neurological disorders such as congenital hydrocephalus, Dandy-Walker syndrome, congenital arachnoid cysts requiring surgical treatment, Chiari malformation, syringomyelia, etc.; ② Children with other underlying conditions that may affect the neurological system, such as poliomyelitis, muscular dystrophy, epilepsy, peripheral neuropathy, etc.; ③ Children with severe intellectual disabilities; ④ Children with urethral anomalies such as posterior urethral valves, hypospadias, urethral duplication, etc.

Measurement before and after SDR

Motor function

To comprehensively assess the motor function of children with SCP, we utilized the Gross Motor Function Classification System (GMFCS) and the Gross Motor Function Measurement-66 (GMFM-66) as the assessment tools[11–14]. The detailed way of evaluation was listed in supplementary data (Supplementary Table 1).

Muscle tension

To assess the lower limb muscle tone of children with SCP, we utilized the modified Ashworth Scale (mAS) as the assessment tool[15–17]. The mAS is a widely used scale for evaluating muscle tone, particularly suitable for patients with spastic disorders. The muscles assessed include: bilateral adductors, quadriceps, hamstrings, gastrocnemius, tibialis anterior, and soleus. The detailed information of mAS grading system was listed in Supplementary Table 2.

LUTS, constipation and DVSS

According to the diagnostic criteria of the International Children's Continence Society (ICCS), all enrolled children with SCP underwent assessment for LUTS and constipation[18]. LUTS assessment primarily focuses on symptom description rather than quantification, including urgency, frequency and incontinence. Recognizing the variability and developmental characteristics of lower urinary tract function, it is acknowledged that some children under 5 years of age may already have voluntary control over lower urinary tract function. Therefore, in this study, the minimum age for enrolled children was set at 4 years old[18]. The Dysfunctional Voiding Scoring System (DVSS) recommended by the ICCS was used to assess the bladder and bowel function of children with SCP (Supplementary Table 3)[19,20].

Surgical procedure (lumbar-sacral SDR)

Identification of target muscle groups preoperatively

Before SDR, it is essential to assess the muscle spasticity of lower limb by a physical therapist. Muscles such as the adductors, hamstrings, and gastrocnemius with a muscle tone of mAS Grade 2 or higher are marked as target muscles before surgery[21,22]. Extensor muscles (quadriceps, tibialis anterior, and peroneal muscles) of the lower limbs are typically not listed as targets for SDR even if their mAS Grade assessment reaches or exceeds Grade 2.

Intraoperative neurophysiological monitoring channels

During SDR, a total of 15 channels were monitored, including bilateral adductors, quadriceps, hamstrings, tibialis anterior, medial and lateral gastrocnemius, peroneus longus, as well as the anal sphincter. Due to practical considerations regarding monitoring feasibility (the soleus muscle is difficult to monitor EMG activity in an undisturbed manner due to its deep location in the posterior aspect of the lower leg), EMG activity of the soleus muscle was not monitored during SDR.

Surgical procedure

The detailed description of SDR was depicted in Supplementary file (Supplementary Fig. 1). To summarize, patients were positioned prone, with needle electrodes inserted into the anal sphincter muscle and various lower limb muscles for intraoperative neurophysiological monitoring. A midline longitudinal skin incision was made, exposing the L2 nerve root and cauda equina below the L3 segment for intraoperative testing. Nerve roots/rootlets met the rhizotomy protocol would be partially cut.

Classification of cauda equina nerves and EMG responses elicited after electrical stimulation
Each nerve root/rootlet underwent single-pulse stimulation during SDR. Based on the different EMG responses elicited by nerve stimulation, all cauda equina nerves can be classified into: (1) motor nerves; (2) sensory nerves; (3) sphincter-related nerves (including sensory and motor roots). The differentiation between motor and sensory roots referred to our previously published article. Detailed descriptions of EMG patterns for different types of nerves were listed in Supplementary Fig. 2.

Intraoperative electrophysiological monitoring setup, stimulation protocol and rhizotomy protocol
The Cadwell-Cascade Elite intraoperative monitoring system was utilized to complete the intraoperative electrophysiological monitoring. Single-pulse electrical stimulation was primarily used to stimulate nerve fibers during SDR. The stimulation parameters were set as follows: stimulation interval of 1 millisecond, stimulation frequency of 0.5 Hz, pulse width of 0.2 milliseconds. When recording electrical stimulation output, a bandpass filter range of 30–3000 Hz was used, with an analysis time range of 100 milliseconds and a sensitivity of 200 μV. The maximum electrical charge for stimulating nerve roots was set at 4.0 milliamperes. Train stimulation was also used to help decision of transecting a nerve root/rootlet during SDR.

Each nerve was stimulated with 0 mA as the starting point for stimulation, and stimulation intensity was increased in increments of 0.01 mA (with a rate not exceeding 0.05 mA/s). During stimulation, close attention was paid to the EMG output in the monitored muscle channels. Stimulation would be stopped if either of the following was observed: ① stable EMG waveform amplitudes exceeding 50 μV in the anal sphincter channel, or ② stable EMG waveform amplitudes exceeding 200 μV in any monitored channel other than the anal sphincter. The stimulation intensity at this point was recorded as the threshold for that nerve root/rootlet, and the EMG output was saved. After recording the threshold and EMG output, each nerve root/rootlet needed to be assessed promptly to determine: ① whether the tested nerve root was a motor root; ② whether the tested nerve root was sphincter-related; ③ whether the tested nerve root predominantly innervates the target muscle groups (see Supplementary Fig. 3). The goal of intraoperative electrophysiological monitoring during SDR was to identify the sensory nerves primarily innervating the target muscle groups but not affecting the anal sphincter and performed partial transection to reduce sensory input to the target muscle groups, thereby lowering their muscle tone postoperatively[23].

Postoperative care and rehabilitation exercises
All patients received regular and standardized rehabilitation therapy after SDR, and underwent regular follow-up examinations. Detailed rehabilitation therapy plans can be found in the Supplementary Fig. 4.

Intraoperative electrophysiological monitoring data
To gain a deeper understanding of the intraoperative electrophysiological data in SDR, we collected the following intraoperative electrophysiological data:

(1) Number of Detected and Sectioned Nerves during SDR.
(2) Number and Proportion of Sphincter-related Sensory Nerves with Anal Sphincter-Induced EMG Greater than 20μV among Sectioned Nerves: We particularly focused on the sectioned lower limb sensory nerves and recorded the number of nerves with anal sphincter-induced EMG greater than 20μV, and calculated the proportion of these nerves among the sectioned nerves.

Statistical analysis
R Studio (Version 4.3.2) was employed for data analysis and visualization. The methods used for data description are as follows: normally distributed data are expressed as mean ± standard deviation, while non-normally distributed data are expressed as median [first quartile-third quartile]. For comparing count data, the chi-square test was used. For comparing two groups of metric data, the t-test/ paired t-test was used for normally distributed data, and the Mann-Whitney test / Wilcoxon signed-rank test was used for non-normally distributed data. For comparing multiple groups of metric data, one-way analysis of variance (ANOVA) was used for normally distributed data, with post-hoc tests (multiple comparison methods) employing Bonferroni correction. For non-normally distributed metric data involving multiple groups, Kruskal-Wallis one-way ANOVA was used, with post-hoc tests (multiple comparison methods) employing Dunn's test. Spearman analysis was used for correlation analysis. The significance level for statistical tests was set at $P < 0.05$.

Results
Demographic information
This study included a total of 247 pediatric patients, comprising 171 males and 76 females. The age ranged from 4 to 16 years, with a median age of 6.0 [5.0–8.0] years old. There were 169 cases of premature birth and 78 cases of full-term birth. Among them, 95 cases of cesarean section and 152 cases of vaginal delivery. There were 27 cases of spastic hemiplegia, 150 cases of spastic diplegia, and 70 cases of spastic quadriplegia. Regarding the GMFCS, 26 patients were classified as level I, 70 as level II, 91 as level III, 55 as level IV, and 5 as level V, respectively. The average GMFM-66 score before SDR was 58.8 ± 13.2.

LUTS and constipation before SDR
Among the enrolled patients, 5 children required the use of diapers due to poor urinary and bowel control, and 94/242 of SCP patients experienced at least one type of LUTS, with 52 cases of urgency, 38 cases of frequency, and 30 cases of incontinence. Additionally, there were 30 cases in which multiple LUTS occurred simultaneously. The proportion of patients having LUTS differed according to the level of gross motor function

before surgery: 30.7% for GMFCS level I, 27.1% for level II, 49.5% for level III, 41.8% for level IV, and 80% for level V, respectively ($\chi^2 = 12.5$, $P < 0.05$). Before surgery, there were 68 cases of patients with constipation. The proportion of constipation occurrence varied among patients with different levels of gross motor function: 7.7% for GMFCS level I, 12.9% for level II, 33.0% for level III, 50.9% for level IV, and 80% for level V, respectively ($\chi^2 = 34.0$, $P < 0.0001$). A contingency table analysis revealed that among the 247 children included in the study, 50 had both LUTS and constipation, 49 had LUTS without constipation, 23 had constipation without LUTS, and 125 had neither LUTS nor constipation. The odds ratio for the association between LUTS and constipation was calculated to be approximately 5.54 (95% CI: [2.35–13.05], $P < 0.0001$). The median DVSS score for all enrolled patients was 0 [0–4.0]. There were differences in DVSS scores among patients with different levels of motor function (Fig. 1A), and a negative correlation between DVSS score and preoperative GMFM-66 score were found (Fig. 1B, R=-0.32, $P < 0.0001$).

Intraoperative electrophysiological details

During SDR, a median of 55 [48–63] nerve roots/rootlets were tested per surgery. Among these, there were a median of 21 [17–27] sensory roots, 11 [10–12] motor roots, and 23 [17–28] sphincter-related nerves. There were no differences in the total number of detected nerves among patients with different levels of gross motor function. During the operation, the median of sensory nerve roots meeting the criteria for partial resection was 7 [5–10] roots. There were differences in the number of resected nerve roots among patients with different levels of gross motor function (Fig. 2).

We recorded the evoked EMG output of each nerve fiber and count the number of nerves whose evoked anal sphincter EMG amplitudes exceed 20μV at threshold stimulation intensity. Among all enrolled patients, the median number of nerves that could simultaneously evoke anal sphincter EMG amplitudes exceeding 20μV was 1.0 [0–3.0] nerve roots/rootlets, accounting for 20% [0–33.3%] of all resected nerves. There were differences in the number of nerves evoking anal sphincter EMG amplitudes exceeding 20μV among patients with different levels of motor function during SDR (Fig. 3). Patients at GMFCS level I had fewer resected nerve roots compared to those at GMFCS level III (0 vs. 2.0, $P < 0.01$), GMFCS level IV (0 vs. 1.0, $P < 0.01$), and GMFCS level V (0 vs. 2.0, $P < 0.05$).

Spasticity and motor function after SDR

All 247 enrolled patients underwent follow-up after SDR, with an average follow-up duration of 4.1 ± 0.6 years. The results showed the degree of improvement in lower limb muscle tone after SDR (Supplementary Table 4). After SDR, patients showed varying degrees of improvement in motor function (Table 1). At the last follow-up, the GMFM-66 motor function score of the patients increased from 58.8 ± 13.2 points preoperatively to 65.4 ± 14.0 points ($P < 0.0001$), and there was a difference in the improvement of GMFM-66 scores after surgery

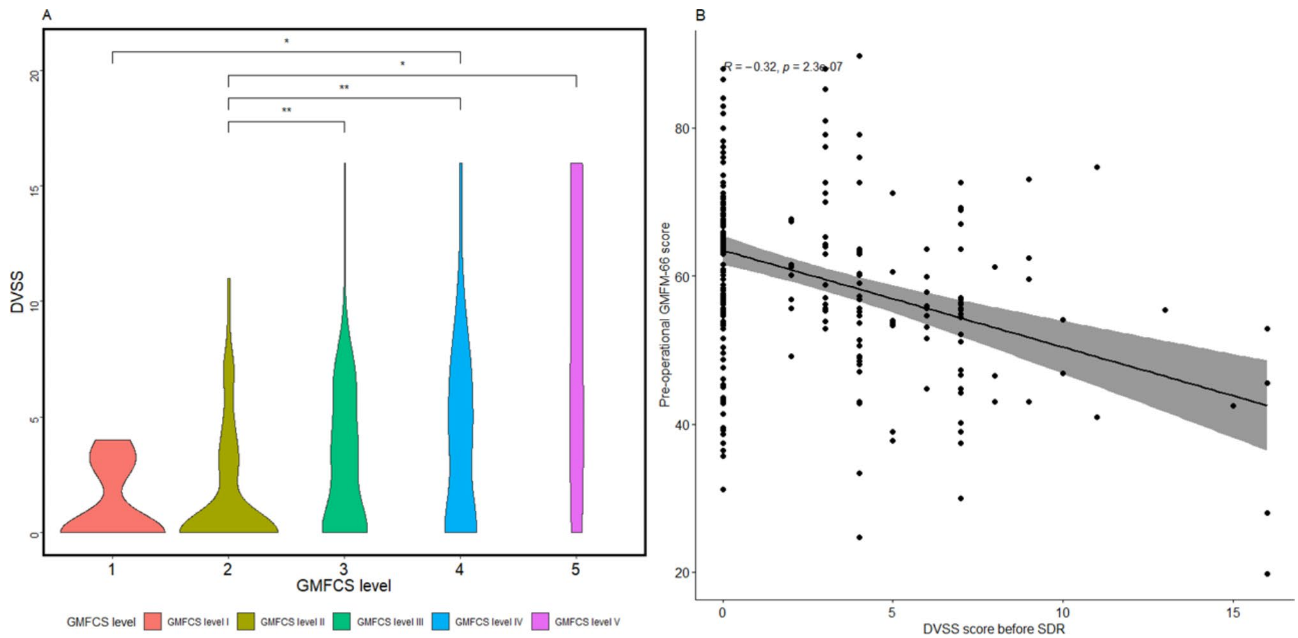

Fig. 1. The Preoperative DVSS Scores of Spastic Cerebral Palsy with Different GMFCS levels and the correlation between GMFM-66 scores and DVSS scores preoperatively. (**A**). Preoperative DVSS scores of children with different GMFCS levels. The median DVSS score for patients at GMFCS level IV was significantly higher than that for those at level I (4.0 vs. 0, $P < 0.05$), for patients at level V was significantly higher than that for those at level II (7.0 vs. 0, $P < 0.05$), for patients at level IV was significantly higher than that for those at level II (4.0 vs. 0, $P < 0.01$), and for patients at level III was significantly higher than that for those at level II (3.0 vs. 0, $P < 0.01$). (**B**). Correlation between preoperative DVSS scores and preoperative GMFM-66 scores. Statistical symbols *： $P < 0.05$， **： $P < 0.01$.

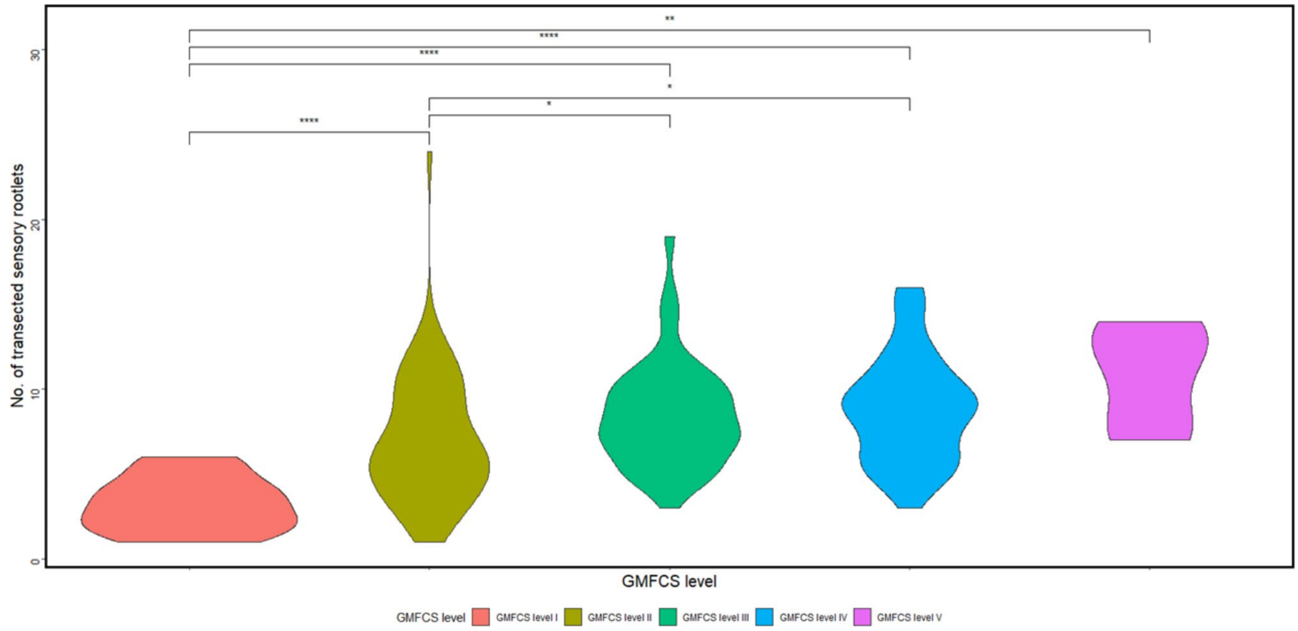

Fig. 2. Number of Transected Nerve Roots/rootlets During SDR in Spastic Cerebral Palsy with Different Motor Function. Patients at GMFCS level I had a lower median number of resected nerve roots compared to those at GMFCS level II (3.0 vs. 6.0, $P < 0.0001$), GMFCS level III (3.0 vs. 8.0, $P < 0.0001$), GMFCS level IV (3.0 vs. 9.0, $P < 0.0001$), and GMFCS level V (3.0 vs. 12.0, $P < 0.01$). Patients at GMFCS level II had a lower median number of resected nerve roots compared to those at GMFCS level III (6.0 vs. 8.0, $P < 0.0001$) and GMFCS level IV (6.0 vs. 9.0, $P < 0.0001$). Statistical symbols *：$P < 0.05$，**：$P < 0.01$，****：$P < 0.0001$.

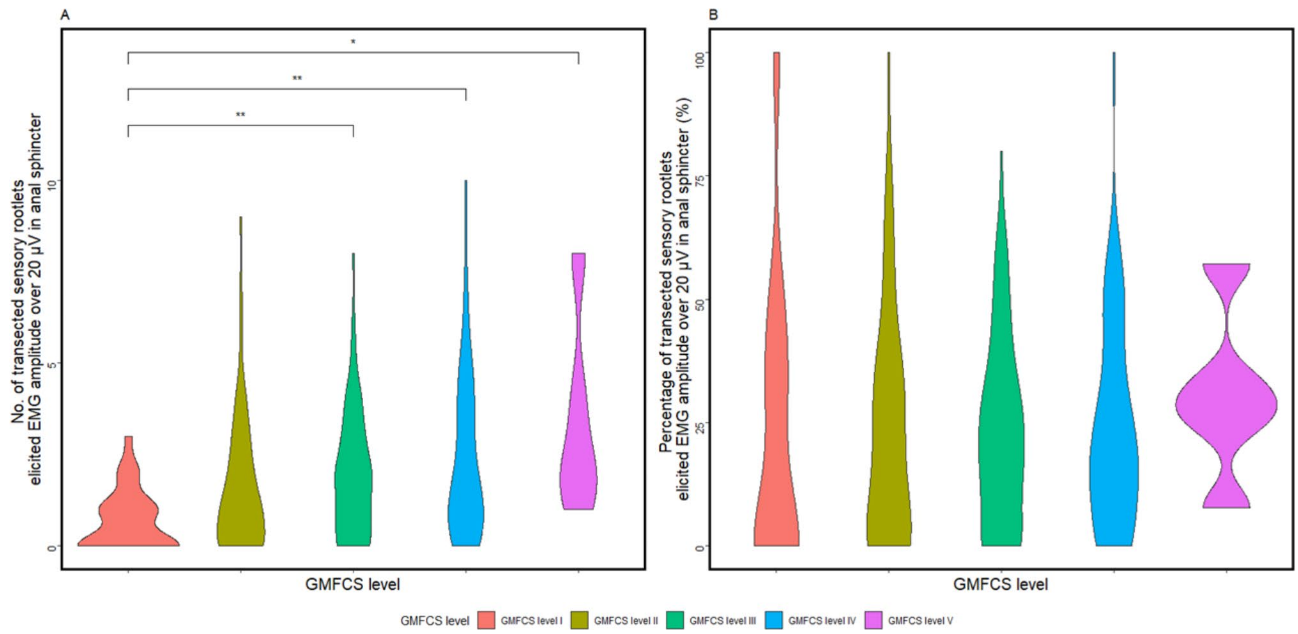

Fig. 3. Differences in Intraoperative Electrophysiological Data Among Spastic Cerebral Palsy with Different GMFCS Levels. (**A**). The number of nerves inducing EMG amplitudes exceeding 20μV in anal sphincter at threshold stimulation intensity, (**B**) The proportion of nerves inducing EMG amplitudes exceeding 20μV in anal sphincter at threshold stimulation intensity. Statistical symbols. *：$P < 0.05$，**：$P < 0.01$.

	GMFCS I	GMFCS II	GMFCS III	GMFCS IV	GMFCS V
Pre-op GMFM-66 score	82.3 ± 4.1	69.5 ± 4.5	57.1 ± 3.8	44.5 ± 5.4	28.3 ± 7.2
Post-op GMFM-66 score	85.8 ± 4.4	77.3 ± 4.7	62.0 ± 3.9	49.2 ± 6.2	30.3 ± 8.3
GMFM-66 score improvement	4.0(2.0, 4.8)	7.1(5.5, 8.8)	5.1(3.2, 6.7)	4.0(2.0, 5.0)	2.0(1.0, 3.0)

Table 1. GMFM-66 scores before and after SDR in spastic cerebral palsy of different motor function.

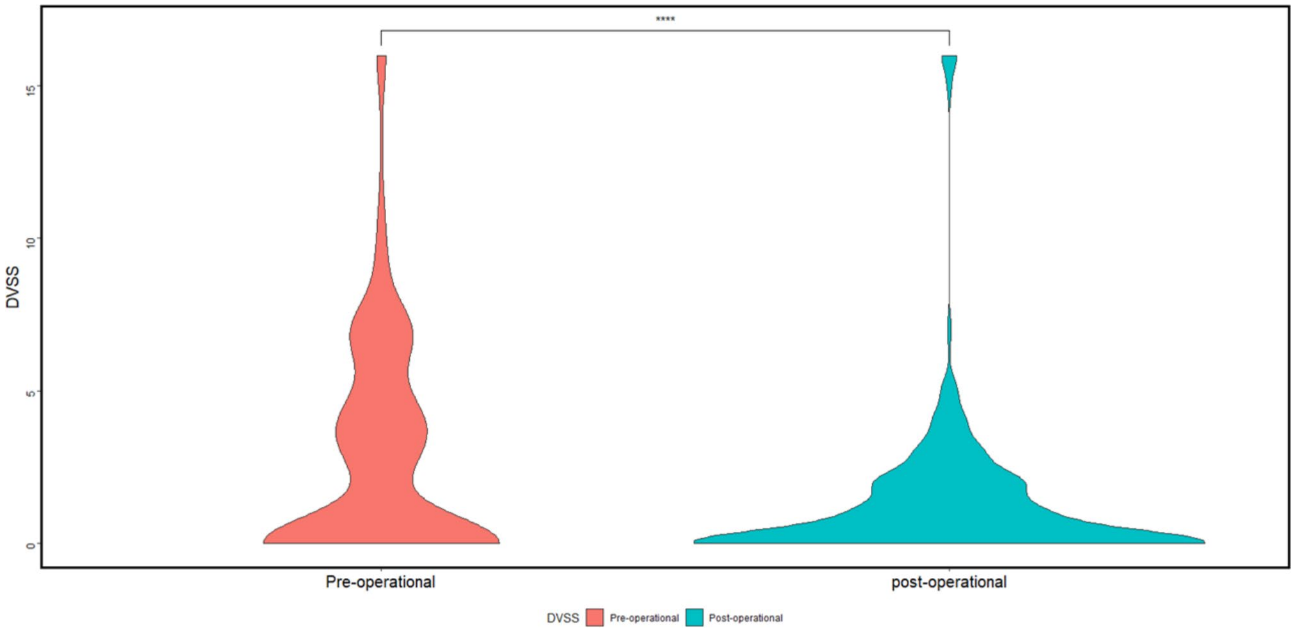

Fig. 4. DVSS score before and after SDR. Statistical symbols. ****： $P < 0.0001$.

	Before SDR (Number of cases)	After SDR (Number of cases)
No LUTS	148	226
LUTS	99	21
No constipation	174	231
Constipation	73	16

Table 2. LUTS and constipation before and after SDR.

among patients with different levels of severity ($P < 0.0001$). Patients at GMFCS levels I, II, and III showed higher postoperative improvements compared to those at GMFCS levels IV and V.

LUTS and constipation and DVSS change after SDR

Before surgery, 121 patients had DVSS score greater than or equal to 1 point, and after SDR, 107 patients experienced varying degrees of score reduction, while the score of the remaining 14 patients showed no significant change (Fig. 4). Before SDR, 126 patients had DVSS scores of 0 point, and after surgery, the DVSS score of 125 patients remained unchanged, with one patient's score increasing by 2 points. There was a significant improvement in LUTS in patients after SDR (Table 2). Before surgery, 99 patients had LUTS or need wearing diaper. After SDR, LUTS improved in 78 patients ($\chi^2 = 66.9$, $P < 0.0001$), and all 5 patients who required diapers before SDR still need wearing diapers after the surgery. Similarly, constipation improved in SCP patients after SDR. Before surgery, there were a total of 73 constipated patients, and after surgery, symptoms improved in 57 patients ($\chi^2 = 44.5$, $P < 0.0001$). No fecal incontinency was found post-operatively.

Patients with preoperative LUTS and constipation symptoms showed no significant differences in the number of nerves detected during SDR, SDR preoperative sacral sensory and motor nerve thresholds compared to patients without LUTS and constipation symptoms before surgery. Among the 78 patients who had LUTS improvement after SDR, the number of nerves in the sensory nerves during surgery simultaneously inducing anal sphincter muscles to exceed 20μV EMG amplitude was 2.0 [0–3.0], exceeding that of patients with no DVSS score change after surgery (Fig. 5A, median 1.0, $P < 0.05$). The proportion of sensory nerves simultaneously

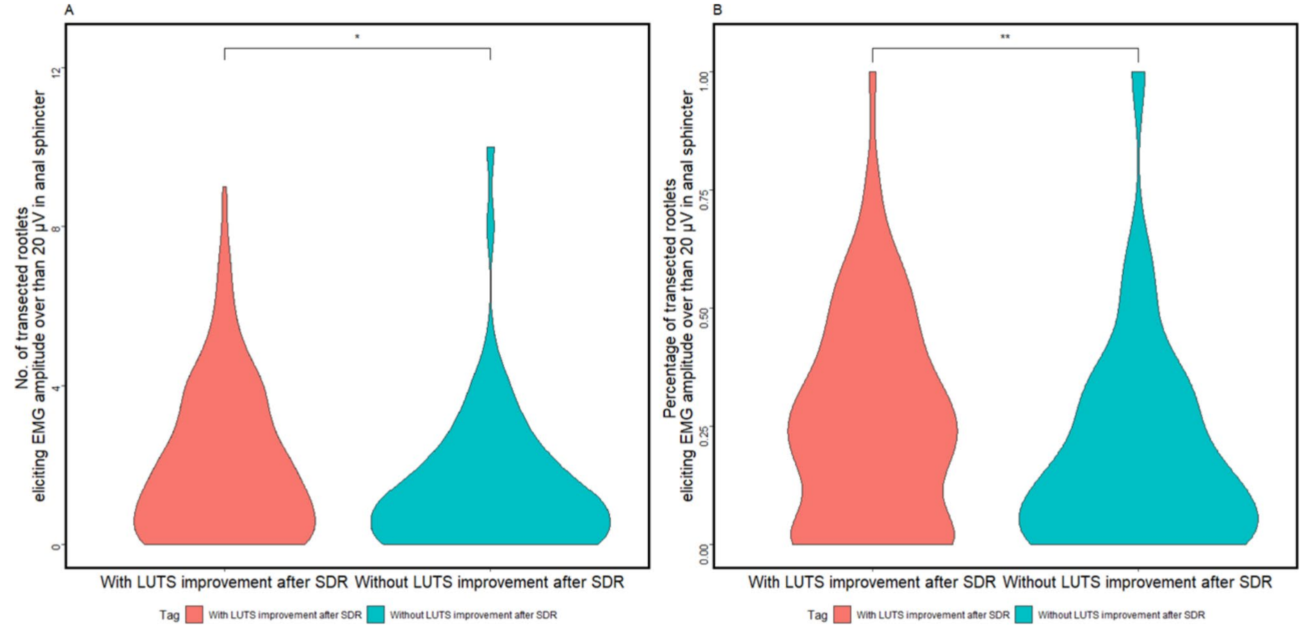

Fig. 5. Comparison of neurophysiological data during sdr between spastic cerebral palsy with post-op LUTS improvement or not. Statistical symbols *：$P < 0.05$，**：$P < 0.01$.

inducing anal sphincter muscles to exceed 20μV EMG amplitude during surgery was also higher than that of patients with no DVSS score change after surgery (Fig. 5B and 22.2% vs. 11.1%, $P < 0.01$).

Discussion

In the enrolled patients, more than one third of the children presented with LUTS, which is consistent with the proportions reported in previous studies[24]. It is found that the proportion of SCP patients present with LUTS increased with poorer motor function, which also coincides with the results of previous studies[25,26]. It is found that children with SCP have not only a high prevalence of LUTS but also a high incidence rate of constipation before SDR. The close relationship between constipation and LUTS may be attributed to the shared embryological origin and innervation of the bladder and rectum[27]. Consequently, dysfunction in one can influence the function of the other. Meanwhile, after SDR, in addition to the reduction in lower limb muscle tone and improvement in motor function, there was an improvement in LUTS and a decrease in DVSS scores among children with SCP. This is consistent with findings reported by previous research: SDR can effectively alleviate urgency, frequency, and incontinence symptoms in children, and increase bladder capacity[5,6].

It is speculated that the improvement in LUTS observed after SDR may be partially attributed to the enhanced mobility and motor function. Previous literature has suggested that poor mobility is associated with incontinence as a probable consequence[24]. In this study, we found that children's motor function improved after SDR, which may have contributed to better access to the washroom. This improved accessibility could lead to a decrease in urinary urgency and incontinence episodes, as children are more likely to reach the toilet in time. It is also found that SDR alleviated constipation in these children, which was like the finding of previous study that treating constipation also improves LUTS[28–30]. These findings highlight the importance of a comprehensive evaluation and management of both bladder and bowel dysfunction in children with SCP, as well as the potential role of SDR in improving both conditions. Further studies are needed to elucidate the precise mechanisms by which SDR improves constipation and LUTS in this population.

What is new is that we found the association between intraoperative electrophysiological data and post-op LUTS improvement. During SDR, we used neurophysiological monitoring systems to stimulate each nerve root/rootlet to achieve the purpose of nerve identification. Electrophysiological monitoring helps surgeons protect motor nerves and nerves related to the sphincter muscles, selecting sensory nerves that innervate spastic muscles to cut[9]. Consequently, in theory, SDR does not affect muscles such as the anal sphincter and the detrusor, which are innervated by the sacral nerves. However, after SDR, along with the alleviation of lower limb muscle spasticity, symptoms of LUTS improved. Currently, there is a lack of empirical evidence to explain why SDR can improve symptoms beyond muscle tone. However, the possible reason is hypothesized as multiple innervations of the cauda equina nerve: sensory nerves transected during SDR primarily induce EMG activity in target muscle groups under electrical stimulation, indicating that transected nerves mainly innervate target muscle groups. However, electrical stimulation often simultaneously induces EMG activity in other muscles, albeit with smaller amplitudes compared to target muscle groups. For example, as shown in Supplementary Fig. 2-C, the nerve primarily innervated the medial gastrocnemius muscle of the left side but also plays a certain role in sphincter muscle innervation, implying that partial severance of such nerves may also affect bladder and bowel function. A recent study indicated that postoperative muscle tone in the quadriceps, which was not targeted during SDR, also decreased, suggesting that transected nerves can also induce EMG activity in muscles such as the quadriceps[10]. Consequently, in children with SCP, the bladder tends to be in a hyperexcitable state, leading to symptoms such as urinary frequency, urgency, and incontinence. If the number/proportion of nerves transected that can simultaneously induce EMG activity in the sphincter muscles is high, then the hyperexcitability of the bladder can be alleviated postoperatively.

Based on our hypothesis, we conducted a retrospective review of our systematically acquired intraoperative electrophysiological data. We recorded the thresholds of sensory nerves and motor nerves related to the sphincter muscles before and after SDR and calculated the number and proportion of nerves that could simultaneously induce EMG activity (> 20μV) in the anal sphincter muscle. We chose a threshold of 20μV for anal sphincter muscle EMG amplitude for the following reasons: ① In the absence of electrical stimulation, the amplitude of each EMG channel of the neurophysiological monitoring system is typically below 10μV, and 20μV is a value at which EMG amplitude can be clearly observed; ② In our center's nerve root stimulation protocol, reaching 200μV in any lower limb muscle channel (or 50μV in the anal sphincter muscle channel) is considered the endpoint of stimulation. Therefore, if a nerve can simultaneously induce anal sphincter EMG amplitudes greater than 20μV, and the ratio of anal sphincter muscle EMG amplitude to the maximum lower limb muscle EMG amplitude is greater than 10%, it is reasonable to conclude that the nerve partially innervates the sphincter muscles.

However, the above inference also raised a question: what if a certain SCP patient does not have lower urinary tract dysfunction before the SDR, and the surgery subsequently reduce the bladder sensory signal input, could this lead to complication after the surgery, manifesting as underactive bladder? Theoretically, such complication is possible. However, based on the data collected from over 200 cases, we have not observed such occurrences. By reviewing the data, we have identified possible reasons: Firstly, there was a negative correlation between the incidence and severity of LUTS in SCP patients and their motor function, meaning that the worse the motor function, the higher the incidence and severity of LUTS. Secondly, the number of nerve roots transected during SDR in SCP patients increased with the severity of the condition. Previous studies have also shown a negative correlation between the number of nerves transected during SDR and the preoperative GMFM-66 score. Furthermore, there were differences in the number of nerve roots with anal sphincter EMG amplitudes exceeding 20μV among SCP patients with different GMFCS levels. In summary, we believe that: (1) Mild SCP patients have a low probability of developing LUTS, as they have fewer transected nerves and fewer nerve roots capable of inducing anal sphincter EMG amplitudes exceeding 20μV, thus resulting in less impact on bladder function after SDR. (2) Conversely, severe SCP patients have a high incidence of LUTS, with more transected nerves and more nerve roots capable of inducing anal sphincter EMG amplitudes exceeding 20μV. Therefore, there is a higher possibility of bladder function improvement after SDR.

Although this study included many SCP patients and contained both pre- and post-SDR control data, there are also limitations to consider. Firstly, the assessment data for LUTS were sourced from scale ratings rather than objective examinations like urodynamic studies, which may introduce some degree of subjectivity. Secondly, the neurophysiological monitoring used in the study was aimed at detecting nerve roots and did not include peripheral-central connectivity neurophysiological monitoring methods such as somatosensory evoked potentials. Finally, due to the lack of quantitative evaluation of bladder status, we cannot quantitatively analyze the changes in bladder function after SDR based on neurophysiological data collected during the surgery. The lack of clear correlation between changes in DVSS scores and intraoperative neurophysiological data limits the guidance value of the results for clinical practice. However, this study represents the largest clinical research on the effects of SDR on bladder function among SDR centers worldwide to date. In future work, larger-scale and more systematic studies are needed to clarify the effects of SDR on bladder function in SCP patients and its potential mechanisms.

Conclusions

Through this study, we accomplished three objectives. LUTS are common in SCP patients, with a higher incidence observed in patients with poorer motor function. SDR effectively reduces lower limb muscle spasticity in SCP patients and improves their motor function. SDR can improve LUTS and constipation in SCP patients. In patients with improved LUTS symptoms after SDR, a higher proportion of sensory nerve roots in the lower limbs, which can simultaneously induce anal sphincter EMG amplitudes exceeding 20μV during surgery, is observed.

Data availability

The datasets used and analyzed during this study are available from the corresponding author on reasonable request.

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Author contributions

W.J. and J.W. contributed equally to this work. W.J., J.W., and Q.Z. designed the study. P.A.R. provided guidance on the study design and methodology. Data collection was performed by W.J., J.W., M.W., S.L., and R.W. Data analysis was carried out by W.J. and J.W. The manuscript was drafted by W.J. and J.W., and all authors contributed to manuscript revisions and approved the final version. Q.Z. and B.X. supervised the project.

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Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

This study was conducted in accordance with the relevant guidelines and the Declaration of Helsinki. It is a retrospective study of clinical data and it has been approved by the Ethics Review Committee, Children's Hospital of Shanghai, Shanghai Jiao Tong University (Approval No: 2020R069-E02). Because of the retrospective nature of the study, the informed consent for inclusion was waived by the ethics committee of Children's Hospital of Shanghai.

Additional information

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