Case-based explanation of standard work tools for selective dorsal rhizotomy for cerebral palsy

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OBJECTIVE Spasticity is a challenging feature of cerebral palsy (CP) that may be managed with selective dorsal rhizotomy (SDR). Although standard work tools (SWTs) have recently been utilized to inform a standard of care for neurosurgical procedures, no SWTs for SDR have been previously described. The authors present the multidisciplinary approach SWTs for SDR used at their institutions to promote consistency in the field and minimize complication rates.

METHODS A multidisciplinary approach was used to define all steps in the SDR pathway. Preoperative, intraoperative, and postoperative workflows were synthesized, with specific efforts to improve mobility through inpatient rehabilitation and minimize infection.

RESULTS The SWTs have been implemented at two institutions for 7 years. An illustrative case of a patient aged 3 years 10 months with a history of premature birth at 29 weeks, spastic-diplegic CP, right-sided periventricular leukomalacia, and developmental delay who underwent L2–S1 SDR is presented.

CONCLUSIONS The authors detail SWTs for SDR developed by a multidisciplinary team with specific steps at all points in the patient pathway. The illustrative case emphasizes that SWTs may help ensure the safety of SDR while maximizing its long-term efficacy for individuals with CP.

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KEYWORDS cerebral palsy; pediatric neurosurgery; prematurity; rhizotomy; standard work tools

Cerebral palsy (CP) commonly causes mobility disorders with a prevalence of 2.11 per 1000 live births that has remained constant regardless of the improved survival of preterm infants.1 CP involves a constellation of motor findings, encompassing spastic, ataxic, dyskinetic, and mixed phenotypes, with spastic as the most prevalent.2 Risk factors for CP include preterm birth, low birth weight, other congenital anomalies, and neonatal intensive care admission.3 Children with CP often have reduced health-related quality of life, with worse quality of life as the severity of CP increases.4

Spasticity, defined as velocity-dependent increased resistance to passive muscle stretch, is a particularly challenging feature of CP to treat.5 The clinical assessment of spasticity is often heterogeneous.6 Intrathecal baclofen (ITB) and selective dorsal rhizotomy (SDR) represent the primary surgical strategies used to treat spasticity.7,8 Developed in the 1980s, ITB facilitates increased bioavailability of baclofen relative to oral administration to reduce muscle tone and spasticity.9,10 However, ITB involves high complication rates from infections, CSF leaks, and catheter-related factors.11–13 SDR provides improved mobility, function, and quality of life, with lasting benefits through adolescence and into early adulthood, although long-term evidence is relatively limited.8,14–18 However, SDR involves short-term complications, namely sensory alterations, CSF

ABBREVIATIONS CP = cerebral palsy; EMG = electromyography; GMFCS = Gross Motor Function Classification System; ITB = intrathecal baclofen; PM&R = physical medicine and rehabilitation; SDR = selective dorsal rhizotomy; SWT = standard work tool.

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leaks, and gastrointestinal dysfunction, as well as long-term complications, including sensory and motor changes, spinal deformity, and impaired bladder control. Spinal deformity is particularly likely when a wide laminectomy approach is utilized with multilevel bony exposures.

Historically, patients with hypertonia and nonambulatory status were considered candidates for ITB, while SDR was reserved for children who could ambulate, in an effort to improve gait. A more recent study by Mansur and colleagues indicated that the decision between ITB and SDR is highly dependent on patient-specific factors. When SDR is selected, the preoperative workup, day-of-surgery protocol, postoperative care, and follow-up are highly variable. Our team recently developed standard work tools (SWTs) to inform a standard of care for ITB and dynamic stereoelectroencephalography using ROSA (Zimmer Biomet). The ITB pathway yielded lower complication rates relative to historical cohorts through workflow efficiency and optimization. To date, no study has provided SWTs for SDR for CP. In this paper, we present the multidisciplinary approach SWTs for SDR utilized at our institutions to promote consistency in the field and minimize complication rates.

Methods

Overview

The SWTs were developed over 3 months. An illustrated manual for patients undergoing SDR containing the complete workflow was provided to the multidisciplinary team. The team consists of a neurosurgeon, a neurologist, a neurophysiologist, physical medicine and rehabilitation (PM&R) physicians, pediatricians, a nurse practitioner, surgical nurses, physical therapists, occupational therapists, coordinators, a social worker, an orthotics professional, and anesthesiologists. The workflow is shown in Fig. 1. At our center, SDR is indicated in patients with spastic diplegia. The ideal surgical candidate has spastic CP primarily affecting the lower extremities, a normal intelligence quotient, and strong core strength. We have previously performed SDR for hemi- or triplegic patients in a more focused manner using these SWTs, with good effect.

Preoperative Workflow

The preoperative workflow is shown in Fig. 2. Patients considered for SDR are evaluated by a multidisciplinary movement disorder conference consisting of neurosur-
geons, PM&R physicians, and pediatrics after undergoing appropriate management, such as Botox and physical therapy, by referring providers. Standardized notes in the electronic medical record are used to define trackable data, such as Gross Motor Function Classification System (GMFCS) subscores, gait study, and quality of life assessment with the Pediatric Quality of Life Inventory (PedsQL). The team completes a planning form. The neurosurgical team sends a letter to the referring provider and then books the case, and the movement disorders coordinator sends an email to all stakeholders with the planning form to notify them. Patients undergo gait mapping for a baseline understanding of cadence, velocity, and step length. The gait mapping sophistication varies; the first type is complex analysis paired with electromyography (EMG), and the second type is surface pressure mat walking while being video recorded. Gait kinematics and kinetics are conducted, and oxygen consumption is measured. The neurosurgical coordinator calls the family to discuss the procedure and reminds the family to cleanse the patient’s skin from shoulder blades to gluteal cleft and flank to flank with over-the-counter chlorhexidine wash each day for 3 days before surgery and the morning of surgery. The physiatrist and neurosurgeon identify sectioning percentages per nerve root following the checklist.

Operative Workflow

The operative workflow is shown in Fig. 3. The neurosurgical team obtains consent for the procedure after explaining the risks and benefits of the procedure and expected hospital course. Following transport to the operating room and intubation, the anesthesia team administers cefazolin 25 mg/kg (preferable) within 60 minutes of incision. The neurosurgical team cleans the surgical site with alcohol and Chloraprep and then places an Ioban antimicrobial incise drape. Leg function is observed in the nonsterile field and available to the physiatrist for manual muscle examination throughout the procedure. The neurosurgical team pauses and reviews the operative planning sheet (Fig. 4). The procedure involves an osteoplastic laminoplasty over the conus medullaris (T12–L2), intradural nerve root dissection, and neurophysiology-guided dorsal rootlet division.

Each dorsal root is isolated, and triggered EMG using Gilette nerve hooks is performed to confirm both level and muscle innervation threshold. The muscle groups covered include the iliopsoas (L1), adductor longus (L2, L3, L4), vastus lateralis (L2, L3, L4), biceps femoris (L5, S1), tibialis anterior (L4, L5), gastrocnemius (S1, S2), adductor hallucis (S1, S2), and external anal sphincter (S2, S3, S4). The root is then divided into very small rootlets. Dorsal versus ventral roots are identified, and the threshold is found for each one. On a rolling basis, the neurophysiologist applies a 50-Hz train of 1-second duration to each rootlet, which the neurosurgeon, neurophysiologist, and PM&R physician grade as abnormal or normal. The neurosurgeon cuts the fascicle if all agree that the rootlet is abnormal: grade 3+ (sustained discharges of distant muscle groups, ipsilateral) or 4+ (sustained discharges of contralateral muscle group, with or without ipsilateral muscle group involvement). The neurosurgeon does not cut the fascicle if all agree that the rootlet is normal: grade 0 (unsustained or single discharge to train of stimuli), 1+ (sustained discharge of appropriate muscle group, ipsilateral), or 2+ (sustained discharges of adjacent muscle groups, ipsilateral). The extent of sectioning is also guided by the clinical intention to treat as defined by the physiatrist and neurosurgeon (Fig. 5). The neurophysiologist

![FIG. 3. Operative workflow.](image-url)

![FIG. 4. Operative planning sheet.](image-url)
repeats the stimulation if there is a lack of agreement until all three agree. The procedure is repeated for all nerve roots corresponding to muscle groups stimulated during SDR prior to closure with antibiotic-impregnated sutures. A silver Mepilex dressing is applied. The neurosurgical team places standardized postoperative orders, and the acute pain service provides pain management.

**Postoperative Workflow**

The postoperative workflow is shown in Fig. 6. The patient is admitted to the neurosurgical ward and their vitals are checked every 4 hours. A developmental pediatrician assumes primary care for the patient given the complexity of the disease process and protocols. The patient remains supine for 24 hours and receives cefazolin for 24 hours. The patient’s diet is advanced as tolerated. The neurosurgical team places consultation requests to PM&R, orthotics, physical therapy, and occupational therapy as needed. Once the patient is mobile, the Foley catheter is removed. The acute pain service provides pain and nausea management per an internal protocol using a demand-only patient-controlled Dilaudid anesthesia and synergistic polypharmacy and weans medications by postoperative day 3. Gabapentin is used to ameliorate neuropathic pain and sensation. The silver Mepilex dressing is removed on postoperative day 5. If the dressing falls off before this point, bacitracin is applied for 5 days. No laboratory results or images are obtained unless clinically indicated.

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**FIG. 5. SDR surgical protocol.**

<table>
<thead>
<tr>
<th>Pre-operative:</th>
<th>Rhizotomy Details</th>
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<tbody>
<tr>
<td></td>
<td>Right</td>
</tr>
<tr>
<td></td>
<td>L1 Stimulated</td>
</tr>
<tr>
<td></td>
<td>Sectioned</td>
</tr>
<tr>
<td></td>
<td>Ventral sectioned</td>
</tr>
<tr>
<td></td>
<td>L2 Stimulated</td>
</tr>
<tr>
<td></td>
<td>Sectioned</td>
</tr>
<tr>
<td></td>
<td>Ventral sectioned</td>
</tr>
<tr>
<td></td>
<td>L3 Stimulated</td>
</tr>
<tr>
<td></td>
<td>Sectioned</td>
</tr>
<tr>
<td></td>
<td>Ventral sectioned</td>
</tr>
<tr>
<td></td>
<td>L4 Stimulated</td>
</tr>
<tr>
<td></td>
<td>Sectioned</td>
</tr>
<tr>
<td></td>
<td>Ventral sectioned</td>
</tr>
<tr>
<td></td>
<td>L5 Stimulated</td>
</tr>
<tr>
<td></td>
<td>Sectioned</td>
</tr>
<tr>
<td></td>
<td>Ventral sectioned</td>
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<td></td>
<td>S1 Stimulated</td>
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<tr>
<td></td>
<td>Sectioned</td>
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<tr>
<td></td>
<td>Ventral sectioned</td>
</tr>
</tbody>
</table>

*Pre-operative: Hibiscrub and Chloraprep three nights prior and the morning of surgery*
The patient is admitted to rehabilitation for 2 weeks if nonambulatory or 4–6 weeks if ambulatory and managed per the rehabilitation protocol (Online Appendix) before being transferred to outpatient physical therapy. The neurosurgery team follows the patient after discharge from rehabilitation, conducting evaluations at 6 and 12 months after surgery. The PM&R team conducts a gait assessment at 12 months.

**Study Oversight**

This study was exempt from institutional review board approval. Patient consent was neither required nor sought, as no identifiable information is present.

**Results**

The SWTs have now been implemented at two institutions (Indiana University and Ann & Robert H. Lurie Children’s Hospital of Chicago) for 7 years.

**Illustrative Case**

A male patient aged 3 years 10 months with a history of premature birth at 29 weeks, spastic–diplegic CP, right-sided periventricular leukomalacia, and developmental delay presented in March 2022 for initial evaluation. He received occupational and physical therapy through school. The patient primarily ambulated by crawling at home and school; otherwise, he used a wheelchair. He could walk 50 feet at a time using a rear wheel walker and had an ankle foot orthosis. His hamstrings were “tight” per his mother. He had been receiving Botox injections every 4 months, with some improvement in range of motion on physical therapy but no noted improvement in spasticity. Oral antispasmodic medications had not been tried. On physical examination, the patient had GMFCS level III, with tone affecting gait, mobility, and function. He had modified Ashworth scale grades of 0 symmetrically in the upper extremities bilaterally and 2 in the lower extremity adductors, 0 in the knee flexors, and 1+ in the hamstrings bilaterally. The decision was made to start the patient on oral baclofen 5 mg three times daily. Serial casting was not pursued given the predicted lack of efficacy on tone control.

Because the patient continued to experience spasticity despite the administration of baclofen, he underwent L2–S1 SDR 11 months later, in February 2023. Needle EMG of the lower extremities was performed for intraoperative monitoring bilaterally for L2–S1 at a rate of 4.15 Hz. Muscle reactions were graded, and rootlets were cut based on abnormal spastic reactions (grade 3 or 4). In total, 36 of 136 (26%) sections were cut over 99 minutes (Table 1). The estimated blood loss was 20 mL. There were no complications. The patient’s hospital course was uncomplicated, and he was discharged on postoperative day 5 to inpatient rehabilitation. During inpatient rehabilitation admission, therapy intervention focused on proximal strengthening, progressing to tall kneeling and then standing. Prior to discharge, the patient had progressed to gait training with bilateral solid ankle foot orthosis and de-rotation straps promoting external rotation. Spasticity improved and hypertonia medications were weaned. The patient was discharged after 6 weeks and transitioned to outpatient therapy services for ongoing strengthening and gait training.

**Discussion**

A multidisciplinary approach was used to develop SWTs for SDR to mitigate differences in practice patterns

**TABLE 1. SDR sectioning performed in illustrative case**

<table>
<thead>
<tr>
<th>Nerve</th>
<th>Side</th>
<th>Duration, mins</th>
<th>Total % Cut (cut/tested)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Lt</td>
<td>11</td>
<td>0% (0/0)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>4</td>
<td>0% (0/0)</td>
</tr>
<tr>
<td>L2</td>
<td>Lt</td>
<td>12</td>
<td>14.3% (1/7)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>7</td>
<td>18.2% (2/11)</td>
</tr>
<tr>
<td>L3</td>
<td>Lt</td>
<td>4</td>
<td>18.7% (1/6)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>7</td>
<td>20.0% (2/10)</td>
</tr>
<tr>
<td>L4</td>
<td>Lt</td>
<td>6</td>
<td>33.3% (3/9)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>8</td>
<td>26.3% (5/19)</td>
</tr>
<tr>
<td>L5</td>
<td>Lt</td>
<td>6</td>
<td>35.7% (5/14)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>14</td>
<td>33.3% (9/27)</td>
</tr>
<tr>
<td>S1</td>
<td>Lt</td>
<td>6</td>
<td>27.3% (3/11)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>12</td>
<td>22.7% (5/22)</td>
</tr>
<tr>
<td>S2</td>
<td>Lt</td>
<td>2</td>
<td>0% (0/0)</td>
</tr>
<tr>
<td></td>
<td>Rt</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA = not applicable.
and reduce the rate of complications. We highlight an illustrative case to demonstrate the utility of SWTs for SDR. The patient had technically successful surgery without complications followed by intensive inpatient rehabilitation that yielded improved function.

SDR was developed in the 1960s for spastic CP and has evolved over time. However, variation exists in patient selection and operative approach. Selection criteria may include body structure and function, activity, and personal and environmental factors, but are often not based on standardized measurements. A recent survey on practice patterns from the Cerebral Palsy Research Network (CPRN) indicated that although neurosurgeons agree on performing SDR in older age groups, screening for dystonia with a neurological examination, and being more cautious about SDR in the presence of dystonia, their opinions vary on what is the youngest age or ideal GMFCS level for SDR. Moreover, indications for SDR are expanding as SDR may often yield equivalence to ITB. Operative approaches, including level of exposure, electrophysiological guidance, extent, and classification of nerve roots, are also heterogeneous. Exposure varies from the minimally invasive keyhole interlaminar approach to the open multilevel laminectomy. One study reported that single-level laminectomy provides a higher degree of improvement in ankle dorsiflexion relative to multilevel laminectomy, without a difference in the rate of scoliosis. Another study determined that single-level laminoplasty was least invasive and resulted in an incidence of scoliosis similar to the natural history of ambulatory children with CP.

Increased attention has been placed on quality improvement initiatives in order to enhance the safety and efficacy of neurosurgical procedures. A survey of members of the American Association of Neurological Surgeons/Congress of Neurological Surgeons Joint Section on Pediatric Neurological Surgery indicated that standardized treatment algorithms for common disorders represent an area of opportunity for quality improvement initiatives in pediatric neurosurgery. SWTs aim to provide a standard of care for neurosurgical procedures through a sustained approach. SWTs are a fundamental aspect of the Lean approach for quality improvement, which focuses on continuous process improvement that reduces waste, and form the basis of Kaizen, the philosophy of improving all functions continuously with the incorporation of all stakeholders. Previous studies have found improved operative efficiency and workflow in stereoelectroencephalography and reduced infection rates in ITB implantation. We created SWTs for SDR to minimize variability in patient selection and operative approach. The illustrative case is a proof-of-concept example that underscores the potential of SWTs to maximize the safety and efficacy of SDR. Although SDR has now been implemented at two institutions for 7 years, summarizing group outcomes was not the purpose of this study. Our experience highlights key lessons and directions for SWTs in pediatric neurosurgery, with specific reference to SDR. SWTs are, by nature, collaborative. Incorporating a multidisciplinary team of all individuals involved in the care of children with CP in the development of SWTs is essential to ensure comprehensive care across the entire SDR pathway. This process takes time due to the need for multiple stages of refinement. Providing avenues for continued involvement maintains the commitment of all stakeholders to the SWTs. Assessment scales should be validated to provide meaningful baseline and follow-up data. SWTs provide a detailed plan for patients across the entire pathway of surgery, ranging from preoperative care to postoperative and follow-up care. SWTs must also plan for contingencies, as any given case is rarely completely standard. For example, bacitracin was applied if the Mepilex dressing fell off before postoperative day 5 to prevent infection. Additionally, acceptance of these SWTs by the community of healthcare practitioners who care for children with CP outside of our institutions is essential to investigate their external validity. We note that SWTs are one option for standardizing SDR for children with spastic-diplegic CP, while other options, such as the Delphi consensus methodology, may provide a different lens for developing a standard of care. Future studies should examine the implementation of these SWTs in a larger sample of institutions and use randomized controlled trials to assess the impact of the SWTs on efficacy and safety and identify which components of SWTs are most beneficial. In turn, these studies may refine the SWTs to improve patient selection or operative approaches for SDR.

Limitations

There are limitations to this study. The focus of this article is on standard work and its application to SDR. Acceptance of a workflow should be based on the favorability of patient outcomes. Outcomes are not reported here as many patients have less than 12 months of follow-up, and characterizing outcomes was not the purpose of the study. Although the protocol is feasible at our tertiary care institution, the generalizability to other institutions may be limited, including those without multidisciplinary access, an acute pain service, or PM&R physicians. However, it is important to note that even these components may be pursued in alternate ways at many institutions with similar goals. Moreover, this is a case-based discussion of the workflow with an illustrative case. It is possible that some children with spastic CP may require aspects of care in addition to those in the workflow.

Conclusions

We detail SWTs for SDR developed by a multidisciplinary team with specific series of preoperative, intraoperative, and postoperative steps. The illustrative case emphasizes that SWTs may help ensure the safety of SDR while maximizing its long-term efficacy for individuals with CP. The community-wide adoption of SWTs like these will facilitate multi-institutional and registry-based research by like-minded groups.

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**Disclosures**

Dr. Rosenow reported personal fees from Boston Scientific Neuromodulation, Monteris, Stryker, and AIM Medical Robotics outside the submitted work. Dr. Raskin reported being on the Medical Advisory Board for Synergia and consulting fees from Blackrock Neurotech outside the submitted work.

**Author Contributions**

Conception and design: Shlobin, Shahin, Trierweiler, Rosenow, Raskin. Acquisition of data: Shlobin, Jimenez, Hofflander, Trierweiler, Misasi, Rojas. Analysis and interpretation of data: Shlobin, Jimenez, Hofflander, Trierweiler, Raskin. Drafting the article: Shlobin, Jimenez, Hofflander, Trierweiler, Rojas, Raskin. Critically revising the article: Jimenez, Shahin, Trierweiler, Misasi, Rosenow, Rojas, Raskin. Reviewed submitted version of manuscript: Shlobin, Jimenez, Shahin, Trierweiler, Raskin. Approved the final version of the manuscript on behalf of all authors: Shlobin. Statistical analysis: Raskin. Study supervision: Rosenow, Raskin.

**Supplemental Information**

Online-Only Content

Supplemental material is available online. Online Appendix. https://thejns.org/doi/suppl/10.3171/2024.3.FOCUS2468.

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