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REVIEW ARTICLE

The progress in the treatment of spastic cerebral palsy with selective dorsal rhizotomy (SDR)

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ABSTRACT

Spasticity is the main disabling clinical manifestation of children with cerebral palsy (CP). Selective dorsal rhizotomy (SDR) has been performed for the treatment of spastic CP in Asia for quite some time from 1990. The purpose of this review is to discuss the historical origin and development of SDR. Our goal here is to identify the current patient selection criteria for SDR and to point out indications and contraindications based on the patients with CP, age from 2 to 18 years-old, over 6000 cases, who received SDR surgery with spasticity of muscle tension more than 3 degrees in our center. We also discuss evidence-based approaches on how to evaluate postoperative patient outcomes of SDR and how complications can be avoided. Finally, we mention progress made in terms of SDR technical advances and how improvements can be made in the future. In conclusion, SDR surgery is a reliable way to improve outcomes of patients with spastic CP and can be done carefully in patients as long as stringent selection criteria are used. However, more research and technological advancements are needed to help address associated complications.

1 Introduction

Cerebral palsy (CP) is a frequently occurring disease in children, and its incidence varies from 1.5 to more than 4 per 1000 live births [1]. Because it is associated with high rates of disability, the disease seriously affects the lives of children and their families, bringing a heavy physical and mental burden. Therefore, finding ways to effectively improve the child's ability to live independently has great benefits for both society and the family.

Spastic CP is the most prevalent type of CP and currently, the most commonly used method for treating limb paralysis is selective posterior rhizotomy. Since the birth of this surgical method, it has evolved substantially. This article will discuss in detail the available treatment methods in terms of the following aspects: historical origins, surgical indications, evaluation and diagnostic modalities, predictive factors, surgical complications, current research on technology

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and surgical improvements, and developing trends in surgery and other treatment options.

2 The historical origin and development

In 1908, Foerster first proposed the concept of lumbosacral root resection for the treatment of limb paralysis. He observed that patients with spinal cord paralysis had hemiplegia but did not develop sputum, so he hypothesized that resection of the dorsal root (sensory branch) may alleviate convulsions. Tietze, building on the ideas of Foerster, completely removed the dorsal roots of L2, L3, L5, and S1, and retained the ventral root (sports branch). With this approach, limb spasm in patients was significantly improved, but at the same time, there was obvious muscle weakness and loss of proprioception. Since 1908, Tietze has performed 45 operations using Foerster's technique, with multiple complications and 8 deaths due to meningitis [2]. Since the earlier years, the procedure has continued to improve. In 1978, Fasano proposed the use of combined intraoperative electrophysiological stimulation and partial resection of the dorsal root, which significantly improved the success rate of selective dorsal rhizotomy (SDR) surgery. Peacock and Arens adopted and further promoted these two techniques in 1980. Currently, these two approaches are still a necessary step in SDR surgery. Before the developments of Dr. Warwick Peacock who changed the surgical region to the cauda equina, the site of SDR remained at the conus medullaris region for decades. Selective dorsal rhizotomy has been performed for the treatment of spastic CP in Asia for quite some time from 1990 [3]. From that time, there has been over 6000 patients with spastic CP, age from 2 to 18 years-old, received SDR surgery in our center.

3 Patient selection criteria among athetosis, dystonia, ataxia, atonia and spastic CP

All cases published in the Chinese language discussing poor outcomes after SDR were included in the analysis. The common causes of poor outcomes included the following: 1) Patients with other diseases who were misdiagnosed with SDR. 2) The type of SDR was unclear, and symptoms were often incorrectly categorized; for example, athetosis, dystonia, ataxia, atonia, and SDR were misdiagnosed as spastic CP. In these situations, a wrong diagnosis and surgery would inevitably lead to poor outcomes. If patients with hereditary spastic paraplegia are misdiagnosed as having spastic SDR and undergo SDR surgery, some patients might improve in the short-term; however, patients would likely have sputum production dysfunction due to later stage developments of the disease. In addition, factors such as the presence of progressive muscular dystrophy (fake hypertrophy), patient's appearing normal at birth, disease development at a certain age after onset, progressive exacerbation of the disease, when muscle fiber shows proliferation, hypertrophy, and rupture with inflammatory infiltrates in the intercellular substance, it means the gastrocnemius muscle biopsy is positive. The muscle biopsy associated with pathogenic gene detection technology can be used as a basis for differential diagnosis. This disease must not be treated with SDR surgery. Also, other childhood diseases that affect the limbs, such as congenital clubfoot, spinal deformities, spinal cord syndrome, and poliomyelitis, should be differentiated from spastic SDR. For these other diseases, SDR surgery cannot be performed.

3.1 Identifying the correct indications for SDR is fundamental treatment success [4]

To date, a global consensus has not been reached on indications for SDR surgery which can sometimes differ significantly from institution to institution. The indications for surgery are currently based on clinical experience rather than evidence-based medicine.

What is known now is that not all patients with SDR improve through SDR surgery. Currently, there are confirmed positive outcomes associated with SDR in patients with spastic CP except for those with athetosis, dystonia, ataxia, atonia SDR [5].

In addition, not all degrees of spastic SDR improve after SDR surgery in a similar way. Therefore, clearly defined criteria are important for studies that compare surgical outcomes. Although no consensus has yet been reached, it is necessary to emphasize the establishment of different treatment goals for those in need of SDR surgery with different degrees of spasm, because the intended purpose of this procedure is definitely different for children with better functioning [Gross Motor Function Classification System (GMFCS) levels I–III] or worse (GMFCS levels IV–V) [5].

The SDR criteria should be classified into different domains according to the International Classification of Functioning, Disability and Health model (ICF-model) domains including "body structure and function", "activity", "participation", and "personal and environmental factors" [6]. However, the current published research has not yet reached this standard.

Some indications and counter-indications for SDR have been reported; studies show SDR treatment should be based on standardized and reproducible measurement methods, such as ICF-model domains. If not, the details of the methods should be provided. The multidisciplinary team should provide the criteria instead of just a single neurosurgeon.

3.2 Patients with differential functional levels should have different SDR goals

McLaughlin et al. [7] conducted a meta-analysis on three randomized controlled trials and found that, after 9 months to 2 years, the gross motor function of those who underwent SDR combined with physical therapy demonstrated significant improvement compared to those who underwent physical therapy alone. Since SDR is an irreversible surgical procedure, improper selection of surgical indications may induce a negative impact on a patient's motor function, strict surgical criteria must be specified [7]. For example, a reduction in spasms caused by SDR surgery may be accompanied by muscle weakness in the lower limbs, which may lead to worsening gait performance.

The SDR selection criteria reported in these articles are consistent with our experience. However, who decides the surgical plan is not exactly the same. The definition of treatment goals is also part of the SDR selection criteria. Therapeutic goals are particularly important in rehabilitation medicine because they can assess the effectiveness of interventions. This is especially important for SDR, because this procedure necessarily requires different treatment goals for children with different preoperative functional states. Funk et al. [8] confirmed that SDR holds a solid position in the treatment of children with CP. They believed that children with SDR between the ages of 4 and 7 and preoperative gross motor function measures between 65% and 85% benefit the most from SDR. Kim et al. [9] did a retrospective analysis which was performed to determine whether there are preoperative clinical features predictive of poor prognosis after SDR surgery in children with spastic SDR. They believed that accurate preoperative diagnosis is the strongest

predictor of good outcomes after SDR. In addition, the delay in mental development only suggests predictive power in univariate models, which indicates that it may have a certain prognostic value, but less than accurate diagnostic value. Nicolini-Panisson et al. [10] reviewed 18 studies from which distinct selection criteria were identified for SDR referred to as the five "s" criteria: spastic – lower limb spasticity interfering with functionality; strength – adequate lower limb muscle strength and control; straight – adequate trunk and head control without fixed orthopedic deformity; slim – being thin; and smart – not having significant cognitive deficits. Also, criteria including good family support are cited, as well as good rehabilitation. Buizer et al. [11] retrospectively examined the effects of SDR in non-walking children with severe spasticity. They found that SDR can reduce the difficulty of daily care. However, many patients still have problems with daily care after SDR. Although the degree of spasm is reduced, it does not reduce pain. Therefore, the degree of acceptance varies among different caregivers. At times other orthopedic surgery approaches are needed to resolve associated problems.

From our perspective, the "selection" should include three key factors: appropriate patient selection, identifying the correct nerve segment for undergoing rhizotomy and selectively cutting off the posterior root fiber with a low threshold which number will show on the screen of intraoperative electrical stimulator. These three selection steps are indispensable, and can help substantially with appropriate patient selection to ensure good outcomes. The following indications and contraindications should be strictly followed:

Indications

1. Spasticity with muscle tension more than 3 degrees.
2. Limb soft tissue is free of deformities or only mild deformities.
3. Trunk and limbs have a certain ability to perform exercise.
4. Sufficient level of intelligence for rehabilitation training.
5. Patients aged 4–6 years (associated with better outcomes).
6. Mixture of SDR but mainly spasticity.
7. Severe spastic paralysis and stiffness, affecting daily life and care.

Contraindications

1. Mental retardation, no mental capacity to perform postoperative rehabilitation training.
2. Weak muscle tension and strength of the limbs.
3. Vertebral body disease.
4. Severe contractures and deformity of limbs.
5. Severe deformity of the spine.
6. Severe epilepsy.

4 Outcome indicators

4.1 Spasticity

Park et al. [12] reviewed 85 outcome studies from 12 countries between 1990 and 2017. The published results mostly support SDR. In adults followed for 20 to 28 years, SDR was found to permanently reduce spasticity and avoid complications in patients with spastic CP. Early improvement after SDR consistently showed how the procedure improved quality of life. In addition, most patients after SDR recommended the procedure to others. SDR is therefore now a recognized option for threating spastic CP.

4.2 Activities of daily living

Mittal et al. [13] reported that significant improvements in mobility and self-care in regard to the functional skills dimension were shown within 1 year after SPR. The range of activity scores before the operation, 1, 3, and 5 years

after the operation were 56, 64, 77.2, and 77.8, respectively. In the 1-, 3-, and 5-year evaluations after surgery, the self-care scores increased from 59 points before surgery to 67.9%, 81.6%, and 82.4%, respectively.

Tedroff et al. [14] reported that in a prospective cohort of 18 children, the spasm-reducing effect of SDR did not improve long-term function or prevent contracture, but was able to reduce the pain often experienced by CP patients.

While Josenby et al. [15] explored changes in performance in daily activities (self-care and mobility) 10 years after SDR, and found that all children receiving SDR and physical therapy showed improved limb function and daily mobility within 10 years after surgery. Long-term changes in functional performance were found to be associated with GMFCS instead of age. In children with GMFCS III, IV, and V levels, no upper-limit effect of the Pediatric Evaluation of Disability Inventory (PEDI) scale score was observed during the 10-year follow-up period.

4.3 Hip geometry

Floeter et al. [16] evaluated the changes in hip geometry after SDR in 33 ambulatory children with SDR. The migration percentage, acetabular index, and anteversion were evaluated. The results confirmed that SDR can improve hip geometry and function in children with ambulatory CP during an average of 18 months of follow-up.

Silva et al. [17] reviewed hip dislocation rates and the need for further hip surgery in patients who underwent SDR and who were also registered for The Intrathecal Baclofen Program (ITBP). They found that in the SDR group, 25% of hip joints were reconstructed, compared with 32% in the ITBP group. However, there was no significant difference in the rate of secondary hip reconstruction or dislocation in patients with non-ambulatory SDR.

4.4 Gross motor function measure assessments

McLaughlin et al. [7] performed a meta-analysis of three randomized clinical trials on children with spastic diplegia who received either an SDR plus physiotherapy (SDR+PT) or PT without SDR (PT-only). Based on their clinical experience, they speculated that SDR may be most effective for children aged 3 to 8 years with functional levels of GMFCS III and IV.

Ailon et al. [18] reviewed a database of patients who received SDR at British Columbia Children's Hospital. They found that SDR surgery continued to reduce spasms after 10 years. There were early improvements in existing motor function; however, the improvements decreased in those at GMFCS II and III levels during the long-term follow-up and were not sustained in those at GMFCS IV and V levels.

4.5 Gait

Munger et al. [19] examined a cohort of 24 SDR participants and 11 non-SDR participants who were 16 to 25 years old at follow-up. Patients in the SDR and non-SDR groups demonstrated improved gait quality over a period of more than 10 years. There were no differences in survey measurements of satisfaction between the two groups. These results suggested that alternative treatments in adolescents can achieve similar results to SDR.

MacWilliams et al. [20] evaluated children with diplegic SDR between the ages of 10 and 20. They concluded that the SDR performed in older children was associated with functional declines compared with similar children who underwent orthopedic surgery instead. Their finding suggested that age greater than 10 years might be a contraindication for SDR if the goal is to improve motor skills. They concluded that older children had significantly reduced functional outcomes after SDR compared to children who had not undergone SDR or orthopedic

surgery for the same disease. This suggested that if the goal of treatment is to improve mobility, patients older than 10 years may not be suitable for SDR surgery.

4.6 Range of joint motion

Reynolds et al. [21] reviewed a cohort of 21 adult patients who underwent SDR for CP-related spastic paralysis. After SDR surgery, patients experienced significant improvements in lower extremity passive joint range of motion as well as the improvements in ambulatory ability, spasticity, coordination, pain, overall quality of life, and independence.

4.7 Synergy

Shuman et al. [22] assessed the synergistic effects of three common treatments before and after treatment in 147 children with CP: botulinum toxin type A injections (BTA) ($n = 52$), SDR ($n = 38$), and multi-site orthopedic surgery ($n = 57$). Although the Gait Deviation Index scores improved with 23%, 32%, and 67% of after BTA, SDR, and multi-site orthopedic surgery by more than 5 points, there was little change in the synergy. There was no significant change in the amount of synergy for all treatment groups. After BTA group received a botulinum toxin injection (1.3%) and underwent SDR (1.9%), the total synergy increased, but the change was small. There was no change in level of synergy for any of the treatment groups (mean 0.001 ± 0.10); however, the synergistic activation after SDR did change, and the similarity with typically-developing peers was smaller (-0.03 ± 0.07). Only changes in synergistic activation were associated with changes in gait kinematics or walking speed after treatment. These results suggest that, although synergistic complexity and weighting are challenging in the management of patients with CP, synergistic activation may help reach rehabilitation goals to improve gait.

4.8 Bladder function

Houle et al. [4] evaluated the effect of SDR on bladder function by comparing pre- and post-operative symptoms and urodynamic parameters of children who underwent SDR. They found that at least half of children with spastic SDR had clinically asymptomatic bladder dysfunction. SDR also significantly improved the bladder's storage function while decreasing spasms. They recommend that urodynamic parameters should be included in the evaluation of these children with spastic SDR who are preparing for SDR.

Carraro et al. [23] investigated a surgical outcome assessment tools used to obtain more comprehensive and detailed information on patients with SDR. They referenced different components of the ICF: body structure and function, activity, and participation. The main finding of this article is that a multidimensional clinical function and instrumental evaluation of patients with CP allows us to accurately assess the effects of SDR surgery.

5 Complications

5.1 Pain

Six studies with a follow-up time of 5 to 20 years assessed the incidence of spinal abnormalities and/or back pain after SDR [24–29]. From our perspective, back pain has been experienced in a small number of patients following SDR and was generally associated with lumbar instability in most cases. When no clear lumbar spondylolysis or lumbar spondylolisthesis is found, it can generally be relieved by conservative treatment.

5.2 Limb numbness

Because nerve root fibers are cut intraoperatively, patients inevitably lose some sensation

and proprioception. After some time, the symptoms generally resolve. The symptom duration is positively correlated with the age of the patient at the time of surgery. The older the age, the longer the duration of symptoms [30].

5.3 Transient lower limb muscle strength after SDR

The ambulatory patients with SDR may experience lower limb muscle strength weakness following SDR. This condition may be related to the reduction in lower extremity paralysis after SDR. The weakness experienced can be explained the change in muscle tension from the preoperative to postoperative period. Once the patient demonstrates recovery of active limb function, the weakness can resolve in a short period of time. Of course, the anterior and posterior roots should be strictly identified during the operation to avoid iatrogenic injury that can delay lower extremity recover. During the procedure, it is recommended that the surgeon grasp the area during the posterior root resection to avoid excessive excision than can delay healing and postoperative rehabilitation.

5.4 Spinal deformities

Patients who undergo SDR can experience adverse events such as spinal deformities, including scoliosis and lordosis. Although a substantial number of the patients showed evidence of spinal abnormalities in the follow-up, no comparisons were made to a matched cohort (those who did not receive SDR) and therefore the extent to which SDR is associated with spinal deformities remains unclear. Spinal deformities, especially scoliosis and lordosis, are often observed in conjunction with CP. Approximately 15% to 80% of patients with CP have scoliosis. This wide range in prevalence is due to variations in age, living environment, and severity of neurological dysfunction, all of which affect the extent of physical impairment. Although a large number of patients were found to have spinal abnormalities during follow-up, the correlation between SDR and spinal deformity is currently unclear due to lack of comparison with patients who have not undergone SDR surgery. Since 15% to 80% of patients with CP have scoliosis, it can be considered that spinal deformities–especially scoliosis–often occur simultaneously with SDR. Such a wide prevalence is due to differences in age, natural conditions, and severity of neurological dysfunction, all of which affect the study results [31]. However, it is not clear how much of these abnormalities are caused by SDR.

Spine deformities often occur in children with spastic SDR and for these patients, SDR surgery may worsen, or improve the deformity. Steinbok et al. [32] reviewed the records of 291 children with spastic CP to understand the effects of SDR on lumbar deformity. The results of the data indicated that most patients did have a lumbar deformity after receiving selective SDR and suggested that we should therefore evaluate the patient's spine alignment before and after SDR surgery. Steinbok et al. [32] reviewed data on a total of 104 children who underwent SDR with laminoplasty from L-1 to S-1. They found that 54.8% of children had scoliosis at the last follow-up, and 25% had worsening curvature of 10° or more. When all 104 children who underwent SDR were assessed, the incidence of abnormal kyphosis at the last follow-up visit was 38.6%; 31.8% had worsening curvature of 15°. Their SDR surgery is laminectomy from L-1 to S-1. In addition, at the last follow-up, 54.8% of children had scoliosis. Among them, 25% worsened by more than 10%. At the last follow-up, the incidence of kyphosis was 38.6%, and 31.8% of children had kyphosis more than 15%. Muquit et al. [33] illustrated the feasibility of SDR in combination with scoliosis correction. On the short-term follow-up, improvement in both upper, and lower limb spasms were

observed. The incidence of hyperlordosis at the last follow-up was 21.3%, of which 36% of cases were more severe than 15%. The incidence of spinal deformities in children with SDR is relatively high.

Langerak et al. [26] evaluated the mechanical status of the spine in patients with spastic paraplegia 17 to 26 years after SDR. A comparison of short-term and long-term X-ray results were as follows: scoliosis, 0 and 57%; kyphosis, 0 and 7%; lordosis, 21% and 40%; spondylolysis, 18% and 37%; and one patient had grade I lumbar spondylolisthesis. Magnetic resonance imaging (MRI) scans showed that spinal stenosis accounted for 27%, black disks accounted for 10%, and herniated discs accounted for 3%. The spine deformities appeared to develop over time. However, this change was not significant, and only the progression of mild scoliosis was statistically significant. At the same time, this set of data cannot rule out a natural history of idiopathic spinal deformity in patients with spastic paraplegia who have not received SDR. Harada et al. [34] reported that a group of children with spastic diplegia had a lumbar spondylolisthesis rate of 4%. They also found that 21% had spondyloysis associated with L5. Hennrikus et al. [35] identified a 2% spondylolysis and 2% spondylolisthesis rate in a group of ambulatory patients with SDR. Peter et al. [36, 37] observed 9% of SDR patients with spastic bilateral paralysis who also had spondylolysis or spondylolisthesis (2 have 1-degree spondylolisthesis, and 4 of 5 were able to walk). They also found a correlation between lumbar spondylolisthesis and hyperlordosis. A subsequent paper by this group found a 6% incidence of grade I spondylolisthesis [37]. In these cases, they observed an overall spondylolisthesis incidence of 24%, which was higher than the expected incidence in patients with spastic diplegia. Lumbar spondylolisthesis is more likely to occur after extensive lumbar resection during SDR surgery, especially when the integrity of the lumbar facet joint is damaged. Therefore, extra care must be taken during SDR surgery to ensure the integrity of the facet joints and their capsules. Even if we do not find a statistical correlation between excessive lordosis and spondylolisthesis, persistent excessive lordosis may be a risk factor for the development of spondylolisthesis. Although no patients in their group required surgery for spondylolysis or spondylolisthesis treatment, the high incidence of spinal deformities in this group of patients with spastic paraplegia after SDR is noteworthy.

Due to research design limitations, it is difficult to confirm if deformities have been induced by SDR; they may be just a natural tendency of CP progression in children. In addition, due to the high incidence of spinal deformity in patients with spastic quadriplegia, it is difficult to determine the role of secondary spinal deformities induced by SDR surgery.

5.5 Obesity

Westbom et al. [38] studied the development of weight, height, and body mass index during a 5 year-period following SDR. Based on the current data, it is unclear whether these patient weight gain after SDR has been accelerated by receiving this procedure, or whether patient weight gain is only part of the "obesity epidemic".

6 Technical advancements

The earliest standard technique required L1–S1 laminectomy or laminoplasty to fully visualize all dorsal nerve roots. As technology advances, there are currently two different surgical techniques for exposing the lumbosacral nerve roots. The first method is to expose the conus medullaris by T12–L1 laminectomy and the other approach is to expose the cauda equina distally by performing an L3–S1 laminectomy.

Lazareff et al. [39] assessed differences between rootlets sectioned close to the conus medullaris, according to Fasano's technique [40] and rootlets sectioned distally at the level of the cauda equina according to Peacock's technique [41]. They found that the contents of large myelinated fibers in the posterior root of the spinal nerve obtained by Fasano's technique were significantly higher than that of Peacock's technique. In addition, their early clinical observations showed that patients in Fasano's technology group were able to acquire new motor skills earlier than patients in Peacock's technology group. However, there were only 10 patients in each group. To help identify the best method for improving gait and avoiding potential complications, a large-scale prospective study should be conducted. This will help to verify important findings. Fasano's technique is relatively easy for identifying rootlets. After determining the conus medullaris position on the body based on preoperative lumbar MRI or intraoperative ultrasound, a single level laminectomy can be performed on the L1 vertebra. However, since the operative area is near the conus medullaris, the separation, and plucking of nerve rootlets and electrical stimulation are more likely to cause side effects. Because of this, the operation must be done with the help of a microscope. Peacock's technique is currently more popular in China, which is mostly limited to 2 level-laminectomies; this method allows for a more secure identification of the segmental root [42]. The position of the foraminal exit can be more conveniently used to identify the nerve root than Fasano's technique. In addition, with this method, it is safer to separate nerve bundles and can be done without a microscope [43].

6.1 Laminoplasty with laminae replacement

Disadvantages of multi-segment laminectomy include long incisions, extensive muscle dissection, and potential damage to the ventral roots [41]. There is also evidence that multi-segment laminectomies can cause or exacerbate spinal deformities or postoperative lumbar spondylolisthesis [8, 44].

In order to prevent complications such as postoperative spinal instability, kyphosis, and scoliosis, some spinal surgeons have developed laminoplasty techniques for the SDR procedure to try to maintain the integrity of the posterior spine. Johnson et al. [25] found no difference in the results of laminoplasty versus laminectomy. Thus, both techniques have an equal risk for spinal deformity. Cobb et al. [45] suggested that that laminoplasty instead of laminectomy may prevent the development of lumbar musculoskeletal pain after SDR. Dekopov et al. [46] evaluated 10 year outcomes of SDR in those with CP; they concluded that the degree of spasticity reduction due to SDR is directly dependent on the number of cut roots. The functional result of SDR is affected not only by a decrease in spasticity but also by the functional status and age of the patient at the time of surgery. In all cases, osteoplastic laminoplasty should be used as an approach to prevent spinal cord deformities. Funk et al. [47] introduced a novel laminoplasty technique for complete restoration of the dorsal column. They performed a single-stage SDR on 116 children with CP who had GMFCS levels I to III. Seventy-two children were successfully followed up after surgery, with an average follow-up of 33 months and an average age of 7.2 years. The patients were evaluated by plain X-ray imaging. Of the 72 children, 62 who underwent re-implantation of the laminae were initially considered critical but have achieved refusion. Seven children developed mild scoliosis, the development of which was not associated with GMFCS level or age. The

researchers believed this novel laminoplasty technique provides the least invasive method for SDR. Bales et al. [48] reported on laminectomy technique referred to infra-conus single level laminectomy for SDR, which involves a modified single-segment laminectomy to improve SDR, with the ability to select the number of nerve root resections according to the patient's specific spasm conditions. With this approach, the effectiveness of SDR surgery is still maintained.

6.2 Dorsal root entry zone lesioning

Dorsal root entry zone lesioning (DREZL) using microsurgical techniques was pioneered by Sitthinamsuwan since the 1970s [49].

Sitthinamsuwan et al. [49] compared the outcomes of patients who underwent SDR for lesions in the dorsal root entry zone with the goal of reducing spasms. They used the modified Ashworth Scale and the Adductor Tone Rating Scale to assess the severity of the spasticity. Ambulatory status was also assessed in terms of baseline data.

The results proved that DREZL was more effective in reducing spasms, but more destructive than SDR. DREZL can be selected for bedridden patients, and SDR should be considered for ambulatory patients. Both procedures helped improve ambulatory conditions, but gait improvement was observed only in patients who received SDR.

6.3 Secondary lower extremity spasticity

Reynolds et al. [50] reported one group of patients with lower limb spasm who received SDR surgery for spinal cord injuries. Preoperative long-term spasm was apparent in 2 of the 3 patients who showed improvement following the procedure for up to 9–10 months. Although the third patient also experienced initial relief of the spasticity, it returned to its preoperative severity at 6 months, requiring additional treatment.

Eppinger et al. [51] describe a patient who suffered from hypertension and a hemorrhagic stroke at the age of 46 who underwent SDR (L1–S1). The surgery was performed after two failed intrathecal baclofen pump placements due to repeated infections. The patient's spasticity was significantly reduced after surgery from 4/5 to 1/5 evaluated with the Ashworth Spasticity Score. In addition, the lower extremity tone remained within normal range during the postoperative follow-up period of 3 years.

This exploratory experience suggests that SDR may have a positive effect on the care of patients and quality of life in those with secondary lower extremity spasticity.

7 Summary

Selective spinal neurotomy is a classic neurosurgical intervention, designed to permanently reduce spasticity in the lower limbs and improve mobility in children with CP. Many long-term studies have clearly demonstrated its effectiveness; however, we there is room for technological advancements in this field to help improve SDR. More research is need to better understand the short-term and long-term complications as this will help to improvement the management of patients with CP.

Conflict of interests

The authors declare no conflict of interests in this work.

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