Article published online: 2018-05-10

Surgical Treatment for Spasticity: Selective Dorsal Rhizotomy – Technique and Literature Review

Tratamento cirúrgico para espasticidade: Rizotomia dorsal seletiva – Técnica e revisão da literatura

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Arq Bras Neurocir 2021;40(3):e238–e244.

Abstract

Spasticity is a motor disorder that leads to a resistance to passive joint movement. Cerebral palsy is the most important cause of spasticity and can be caused by several factors, including multiple gestations, alcoholism, infections, hemorrhages, drowning, and traumatic brain injuries, among others. There are many scales that help to measure and monitor the degree of impairment of these patients. The initial treatment should focus on the causal factor, such as tumors, inflammation, degenerative diseases, hydrocephalus, etc. Subsequently, the treatment of spastic musculature includes oral or intrathecal myorelaxants, spinal cord electrostimulation, neurotomies, Lissauer tract lesion, dentatotomy and selective dorsal rhizotomy. The latter is a safe technique, possible to be performed in most centers with neurosurgical support, and it is effective in the treatment of severe spasticity. In this article, the authors describe the surgical technique and conduct a review the literature.

Keywords
- spasticity
- rhizotomy
- cerebral palsy
- electrical stimulation
- surgery

Resumo

A espasticidade é um distúrbio motor que leva a um quadro de resistência ao movimento articular passivo. A paralisia cerebral é a mais importante causa de espasticidade e pode ser causada por diversos fatores, tais como gestações múltiplas, alcoolismo, infecções, hemorragias, afogamento, lesões cerebrais traumáticas, entre

received
October 27, 2017
accepted
December 4, 2017
published online
May 10, 2018

DOI https://doi.org/10.1055/s-0038-1623514.
ISSN 0103-5355.

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Thieme Revinter Publicações Ltda., Rua do Matoso 170, Rio de Janeiro, RJ, CEP 20270-135, Brazil

Palavras-chave
- espasticidade
- rizotomia
- paralisia cerebral
- monitorização intraoperatória
- cirurgia

outros. Existem muitas escalas que ajudam a mensurar e acompanhar o grau de acometimento desses pacientes. O tratamento inicial deve focar no fator causal, como tumores, inflamação, doenças degenerativas, hidrocefalia etc. Posteriormente, o tratamento da musculatura espástica inclui miorrelaxantes orais, intratecais, eletroestimulação medular, neurotomias, lesão do trato de Lissauer, dentatotomia e a rizotomia dorsal seletiva. Esta última é uma técnica segura, possível de ser realizada na maioria dos centros com suporte neurocirúrgico, e eficaz no tratamento da espasticidade grave. No presente, artigo, os autores descrevem a técnica cirúrgica e fazem uma revisão da literatura.

Introduction

Spasticity is a motor disorder characterized by increased muscle tone, leading to a frame of resistance to passive articular movement. In the clinical practice, spasticity is one of the positive signs of upper motor neuron syndrome, which may be accompanied by stiffness, hyperreflexia, primitive reflexes, hypertonia of antigravitary muscles, increased reflexogenic areas, bladder hyperreflexia and clasp knife spasticity. Negative signs can also accompany the clinic examination in these patients, such as paresis, incoordination, fatigue, reduction of tissue elasticity, among others. These signs, under extreme conditions, impair posture, ambulation and self-care. As a direct consequence, we can cite pain, fractures and decubitus ulcers. The worsening of these patients also worsens the quality of life of their respective caregivers. However, the degree of spasticity may help some patients in the maintenance of posture and gait.

Cerebral palsy (CP) is considered one of the most important causes of spasticity, especially in children in whom, when associated with other symptoms such as dystonia, ataxia or stiffness, it leads to a serious disability condition. Even with the advances in care in the neonatal period, an increase in the incidence of CP cases has been observed, which may be related to an increase in the survival of children with very low weight.[1,2]

Etiologically, CP is associated with prenatal events (multiple pregnancies, maternal alcoholism, infections), perinatals (hemorrhages, infections, bradycardia, fetal anoxia) and postnatal (drowning, traumatic brain injury, among others).[3]

To objectively evaluate spasticity, we use quantitative and qualitative indicators that measure the degree and functional repercussion of patients.

The modified Ashworth scale is the most widely used to assess muscle tone. It is a qualitative scale that evaluates the degree of spasticity, measured according to the degree of resistance to passive movement of a segment moved rapidly by an examiner[4] (►**Table 1**). The Penn scale, also widely used in the clinical practice, evaluates the occurrence of spasms (►**Table 1**).

The Tardieu scale measures the intensity of the muscular reaction to passive movement. The arc of motion should be measured by a goniometer. The angle of resistance is the measure relative to the position of minimum stretch for all joints. It is a good option to evaluate the gain after treatment (►**Table 2**).

Gait can be used to evaluate the improvement of spasticity, either in clinical observation or in the gait laboratory using dynamic electromyography (EMG).[5]

Other tests are also used, such as upper limb skill tests and dynamometry hold,[6] measurement of functional independence, Barthel index (quantitative method that evaluates independence in daily activities), quantitative muscle strength and myometrial tests,[7] and the Lyon Université scale, which evaluates automatisms.[8] Initially, spasticity treatment should focus on the causal factor, be it tumor,

Table 1 Modified Ashworth Scale and Penn Scale

Modified Ashworth Scale		Penn Scale
Degree	**Description**	**Description**
0	Normal muscular tonus	Absence of spasms
1	Increase in tone at the beginning or end of the arc of motion	Only spasms precipitated by stimuli
1+	Increased tonus in less than half of the arc of motion, manifested by abrupt tension and followed by minimal resistance	
2	Increased tonus in more than half of the arc of motion, but the affected part is easily mobilized	Spontaneous, strong and irregular spasms, less than one per hour
3	Considerable increase in muscle tone with difficult passive movement	Spontaneous spasms, one or more per hour
4	Rigid parts in flexion or extension	Spontaneous spasms, more than ten per hour

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Table 2 Tardieu Scale

Modified Tardieu Scale	
Degree	**Description**
0	No resistance in the course of passive movement
1	A slight resistance along the course of the passive movement, without precision of the specific angle
2	Clear stiffness at a specific angle, interrupting the stretch, followed by relaxation.
3	Fatigable Clin that lasts less than 10 seconds and appears at a specific angle, while the evaluator is maintaining pressure.
4	Non-fatigable Clin that lasts for more than 10 seconds and appears at a specific angle while the evaluator is maintaining pressure.

inflammation, multiple sclerosis, infectious disease, vascular disease, degenerative disease, hydrocephalus, etc. It is mandatory to prevent or eliminate factors that aggravate spasticity, such as pain, visceral dysfunctions, decubitus ulcers, urinary infections, constipation, heterotopic ossification, ingrown nail, psychological stress and sleep disorders.

Neurosurgical treatment of spasticity is diverse. Intrathecal infusion of myorelaxants, such as baclofen, tizanidine, midazolam, clonidine or morphine, is indicated in patients with preserved motor function and when oral medication is not tolerated or effective. Spinal cord stimulation is an option in mildest cases. Nerve neurotomies such as shutter, sciatic, posterior tibial, fibular or femoral — in the lower limbs — and musculocutaneous, radial or median in the upper limbs, are options for more localized spasticity.

Percutaneous radiofrequency rhizotomy is used in debilitated patients and in the treatment of spastic bladder. The longitudinal myelotomy (longitudinal section of the spinal cord gray matter) is reserved for paraplegics with total impairment of sexual and sphincter function. The lesion of the Lissauer tract and the posterior horn of the spinal cord, proposed by Sindou in 1969, is used in the treatment of spasticity and pain in the lower limbs.[9] Dentatotomy is efficient in the treatment of spasticity evidenced by several casuistics.[10] A selective dorsal rhizotomy (SDR) is a safe, economical and possible technique to be performed in most centers with neurosurgical support, especially pediatric. It is an excellent option in cases of ambulatory patients and quadrispastic children.

Patient Selection

Up to the present moment, there are no completely efficient measures to repair the damage to motor areas that control movement. We have several therapeutic measures for the treatment of spasticity, which include: drug therapy, physical therapy, occupational therapy, applications of botulinum toxin, orthopedic surgery, SDR, in addition to the surgical procedures already explained. The choice for the use of these therapies is extremely important for the patient, since victims of polytraumatism are usually young with long survival, and that children with CP have a mean survival of 20 years.[11]

Selective dorsal rhizotomy is a definitive surgery in which the cauda equina is exposed through osteoplastic laminotomy followed by L2-S1 roots identification.

The results of dorsal rhizotomy have been known since the initial experiments of Sherington (1894) in decerebrated cats. In 1889, Abbe and Bennett described the result of nerve root section with pain control.[1,13] In 1913, Foerster achieved improvement in spasticity after dorsal rhizotomy was performed.[14] Despite good results, dorsal rhizotomy was abandoned for about half a century, due to the comorbidities related to the procedure. Only in 1960s, Gros et al performed partial rhizotomies EMG to help identify dysfunctional nerves.[15] Fasano et al described the criteria for evaluating abnormal motor responses after electrical nerve stimulation.[16] The traditional surgery proposed by Peacock et al consists of a laminotomy from L1 to L5 with a laminectomy of S1-S2.[17] In many services, the level of the approach is varied, including lumbar topographies or medullary cone (MC), aiming to maintain a balance between the preservation of strength and the elimination of spasticity.[3]

The use of electromyography (EMG) to define which dorsal roots were injured also became a reason for discussion due to the variability of the motor response,[18] of the standardization of the technique used in each center,[19] the use of drugs used in anesthetic induction that may interfere with the results of stimulation,[20] and the variability of segmental innervation of the musculature of the lower limbs.[21] One study performed a histological analysis of the sectioned roots of children with CP submitted to SDR, and found that the altered roots in the EMG presented axonal degeneration or demyelination. The roots that appeared normal in the EMG presented minimal histological alterations limited to myelin sheath or demyelination without axonal degeneration, showing that this is a significant method to find the roots that should be sectioned.[22]

Spastic patients present contractions sustained at a stimulation of 50 Hz, but did not present the same contralateral pattern.[21] We have observed in daily practice that a stimulation of 5 Hz is enough to differentiate the motor and sensitive roots . Intraoperative EMG is essential in the identification of the hyperactive roots, contributing to a balance between the reduction of spasticity, bladder control and the preservation of sensitivity.

Studies have shown that SDR is accompanied by significant improvement in several parameters, for example, improvement in motor function,[23–25] significant spasticity reduction,[26] strength gain,[27] increase in movement amplitude,[28,29] and qualitative[30] and quantitative.[31,32] improvements in the upper limbs motor function. Some services use strict criteria to indicate SDR, including the Reimer index, which, when $> 50\%$, can postpone SDR for a period of 6 to 12 months.[3] However, early dorsal rhizotomy would prevent a posterior approach in soft tissues and articular joints.[33]

In the end of the 1980s, the main concern with intraoperative complications was the risk of bronchospasm and

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Fig. 1 Patient intubated on a side stretcher at the surgical table. Appropriate cushions are positioned to avoid decubitus ulcers after the patient is positioned in ventral decubitus.

aspiration pneumonia; However, with the development of new anesthetic techniques and new drugs, the risks were reduced.[34]

Children with CP who evolve with spastic diplegia or tetraplegia, associated with an important spastic component in the lower limbs and minimal impairment in the upper limbs, are the main beneficiaries of this technique. Selective dorsal rhizotomy is not indicated for children under 2 years old because the CP cannot be safely diagnosed in this age group. Dystonia is not an absolute contraindication for surgery, but if there are lesions in basal nuclei with dystonic predominance, other procedures present better results, such as pallidotomy or deep cerebral stimulation. History of multiple orthopedic surgeries counterclaims the procedure due to fixed deformities and muscle weakness.[24]

The main objective of SDR is the reduction of two levels in the Ashworth scale in the deprecated muscular target of the lower limbs. In 50% of the cases, there is also improvement in the upper limbs.[35]

For a good postsurgical outcome, the patient should be duly selected. The clinical examination will define which segments are most affected by the disease and which would be the focus of the rhizotomy. A multidisciplinary team that includes physiatrist, orthopedist, neuropediatrician, psychologist and physical therapist is essential. Posture, sphicnter control, amplitude of the articular movements, whether there are bone or muscular deformities, presence of dystonia, dyskinesias, presence of spasms, gait observation, cognition and comorbidities should be evaluated.

Technique Description

The technique created by Park et al[36] in 1991 differs from the others by removing the lamina of one or two vertebrae, while traditional techniques use laminectomy from five to seven vertebrae.

The patient is sedated and intubated in dorsal decubitus on the lateral stretcher at the surgical table (►**Fig. 1**). Medications that do not alter the EMG activity, such as long-lasting neuromuscular blockers, should be avoided.

After orotracheal intubation, electrodes are introduced bilaterally in the long, large lateral, tibial anterior and medial gastrocnemius muscles (►**Fig. 2**).

Subsequently, the patient is transferred carefully to the ventral decubitus position to maintain soft structures at strategic points of the body to avoid decubitus ulcers. In this position, electrodes are introduced in the perichannel region and the wires are fixed with adhesive in the patient's lower limb (►**Fig. 3**).

We use continuous EMG and a trigger with 14 channels to stimulate the following L1-L2, L2-L3, L3-L4, L5-L5, L5-S1, S1-S2 and on-the-side segments. The interpretation of the EMG result is done by the neurophysiologist. Intraoperative EMG provides valuable information to the neurosurgeon that helps differentiate the sensory root of the motor, in addition, the mapping of the sphincter fibers is a safety factor for not adding deficits to the patient.[37] It is also necessary to have the utmost care with the sacral fibers of S2 to S4 to protect the bladder and sexual function.[38] The patient is kept in a slight position of Trendelenburg to reduce CSF losses. Radioscopy or ultrasonography (in case of children < 10 years old) is used to find the vertebral level to be approached (previously chosen through magnetic resonance imaging [MRI]) to find the MC end, and the incision is made after marking this level (►**Fig. 4**). Since laminectomy should be limited to this segment, it is important that the MC is found.

After making a horizontal incision, with the opening of the subcutaneous cell tissue, we dissected the dorsal musculature away from the thorny process until the slides of the L1 vertebra were exposed, in this example (►**Fig. 5**). After

Fig. 2 Positioning of the EMG electrodes in the muscles of the lower limbs.

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Fig. 3 Patient in ventral decubitus with electrodes positioned on the lower limbs and in the perichannel region.

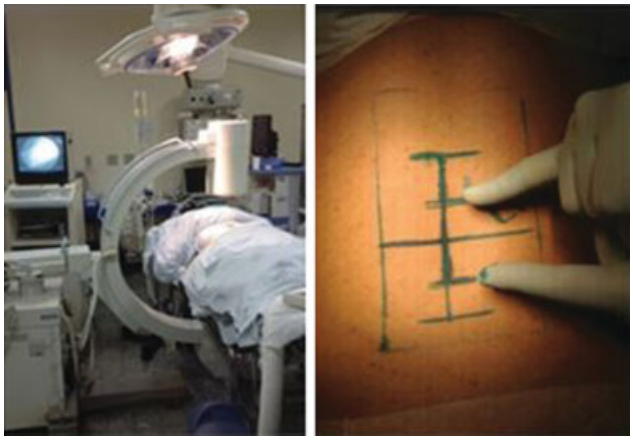

Fig. 4 Left: patient positioned in ventral decubitus at the moment radioscopy is performed to find the level of the spine that will be approached. Right: marking on the skin with the size of the incision.

exposure of the interlaminar space, the yellow ligament is removed with visualization of the dural sac. A linear incision is made to expose the medulla and visualize the MC and the cauda equina.

From this moment, saline solutions should be avoided because they alter the responses of the EMG. The edges of the dura mater are anchored with Vicryl or nylon 4.0 to keep the channel open. The first foramen of the anterior and posterior roots, lateral to the MC, is sought. The root is found, it is divided into four parts to initiate the stimulation to pulses of 0.1 thousandth of a second to a frequency of 0.5 Hz and then 50 Hz, and then identify if we are stimulating motor or sensory fibers. In spasticity, sensory fibers are hyperactive;

Fig. 5 Left: dorsal musculature distanced with visualization of the supraspinatus ligament and spinous process of L1. Right: after laminotomy, exposure of the dural sac to the level of the medullary cone.

In these cases, the most altered part for neurolysis is chosen, preserving those that are in better condition. By not choosing to cut the entire sensory root, it avoids the pain of deafferentation. In the Fig. 6a, we visualize the medullary dura mater at the open L1 level, exposing the MC and the cauda equina. We find the L1 sensory root and use a latex repair to separate the motor from the sensory part (►**Fig. 6b**). Half of the fibers in the L1 dorsal root are cut without stimulation (►**Fig. 6c**). In sequence, we stimulated L2 roots with EMG, isolating the sensory part and separating it into four parts. Again, we stimulate each segment to evaluate the degree of hyperactivity and recorded the electrical patterns of the related muscles. The most injured segments are sectioned.

The root that has already been cut is separated from the others with a tape or vascular shoelace, so as not to risk approaching them again (►**Fig. 6d**). After finding another root and separating again with repair (►**Fig. 6d**), we do a new stimulation and repeat the whole process (►**Figs. 6e** and **6f**) until you approach the whole L2 S2 segment or, depending on the case, those in which the patient has more functional impairment.

The stimulation of nerve roots intraoperatively assesses the functional integrity of the nerve, since it is visually impossible for the surgeon to make this differentiation. As each root is stimulated, a motor response in the musculature of the corresponding segment is perceived, and the information of the action potential is received in the software that analyzes and records the stimuli corresponding to each root. In ►**Fig. 7**, we observe a graphic example of stimulation. The motor latency was 7 seconds and the sensory was 9 seconds. It shows that the L3 root is being stimulated and that the action potential has a late peak to the Yellow Line, which marks the division between motor and sensory, confirming it to be a sensory root. In the left column (in blue) the stimulations are separated into the four parts of the root. It is noted that parts 2 and 3 are more hyperactive. Therefore, these parts can be sectioned, preserving parts 1 and 4.

The advantages of this technique consist in the reduction of spinal deformity, especially in children, if compared with the extensive laminectomy in the traditional technique, improvement of spasticity in the hip, due to the section in the first lumbar dorsal root, reduced surgical access with lower muscular manipulation, and, consequently, less postoperative pain

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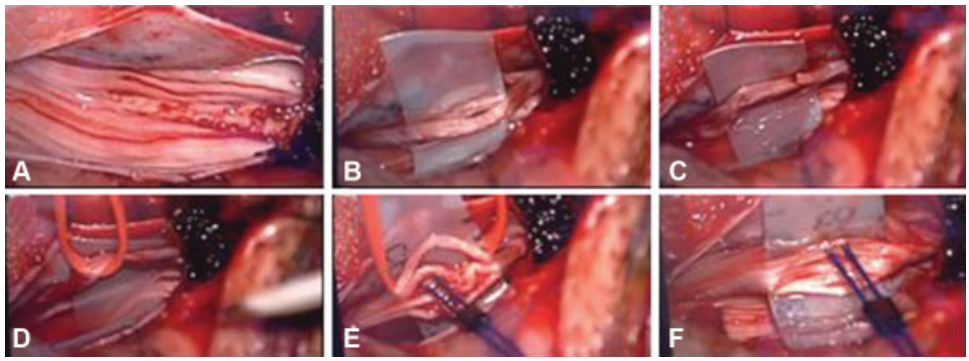

Fig. 6 Intraoperative images showing the open dura mater with visualization of the medullary cone and roots being stimulated during electromyography with bipolar configuration.

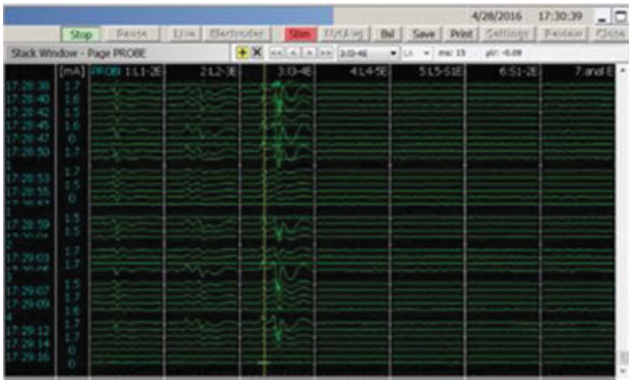

Fig. 7 Stimulation of the L3 segment. We visualize that the wave pulse is to the right of the yellow line and denotes the separation between a motor or sensory impulse. The left side (blue) shows the division of the four parts, evidencing that parts 2 and 3 of the L3 root are hyperactive and should be sectioned.

and early resumption of rehabilitation activities. However, the risks are shared with other procedures such as paraplegia, paralytic bladder, sexual impotence and sensitivity deficit.

A study that included 95 patients treated with SDR in childhood, and accompanied them for periods varying from 20 to 28 years, showed that 91% of the patients submitted to surgery reported that the surgical treatment positively impacted the quality of life. In 42% of the patients, there was improvement in ambulation, 88% would recommend the procedure for other patients and there were no late complications for these patients.[39]

Daunter et al selected patients with CP who underwent SDR in infancy (before 10 years old) and compared them with an unoperated control group. They concluded that the SDR group presented less pain, fatigue and functional decline compared with the nonsurgical group.[40]

The SDR technique by single-segment laminoplasty provides a less invasive approach, and the incidence of scoliosis after this approach is comparable with the natural history of children accompanied as outpatients.[41]

Conclusion

Selective dorsal rhizotomy is efficient in the treatment of severe spasticity. It is a surgery with low morbidity, and electrophysiological stimulation has shown to be efficient in the choice of root segments that should be safely sectioned. However, for a successful treatment, the patient should be rigorously selected. In addition to the functional improvement of the spastic patients, there is an expressive improvement in the quality of life of the caregivers.

Conflicts of Interests

The authors declare that there are no conflicts of interests.

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