Cerebral palsy (CP) is one of the most common causes of chronic disability in childhood, occurring in approximately 2–3 per 1000 live births worldwide.¹,² Spasticity, defined as a velocity-dependent increase in muscle tone, is the most prevalent symptom that significantly limits activity and reduces quality of life in patients with CP.³–⁵ Managing spasticity is a key therapeutic goal in the care of children with CP.⁶

ABBR EVIATIONS
CP = cerebral palsy; DRG = dorsal root ganglion; GMFCS = Gross Motor Function Classification System; GMFM = Gross Motor Function Measure; MAS = modified Ashworth scale; RF = radiofrequency; SDR = selective dorsal rhizotomy.

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Traditional treatment options for spasticity include physical therapy, casting, oral medications such as baclofen or benzodiazepines, botulinum toxin injections, and intrathecal baclofen therapy. However, these treatments have limited efficacy, frequent side effects, and often fail to provide a stable reduction in muscle tone and improved function. Consequently, neurosurgical procedures such as selective dorsal rhizotomy (SDR) have emerged as more definitive treatment options when conservative measures fail. SDR involves laminectomy and division of selective sensory nerve roots, which reduces afferent input into spinal reflex arcs to decrease spasticity. Although SDR can be highly effective, it requires multilevel laminectomies that increase surgical risks, including CSF leaks, infections, hematomas, and spinal deformity. The extensive dissection also leads to significant postoperative pain and a longer rehabilitation process.

Recent studies have explored the use of minimally invasive percutaneous techniques to create radiofrequency (RF) lesions adjacent to the dorsal root ganglion (DRG), thereby interrupting incoming afferent signals to reduce spasticity with less morbidity. Initial case reports and small trials of percutaneous RF-DRG lesions in adult populations with spasticity have shown promising reductions in muscle tone. More recently, Vles et al. conducted a pilot study of RF-DRG lesions in 17 children with severe spastic CP. Although limited by a small sample size and lack of control groups, they noted improvements in muscle tone, pain, and ease of care based on clinical evaluation and caregiver reports. Given the less invasive nature and a potential for reduced complications with RF-DRG lesions compared to traditional SDR, further research is warranted on its efficacy in CP. We hypothesized that RF-DRG lesions can provide significant and stable reduction in tone, resulting in functional gains similar to traditional SDR, but with lower morbidity due to its minimally invasive approach.

The goal of the present study was to evaluate the effects of percutaneous thermal RF ablation of spinal roots on spasticity and motor function in children with spastic CP.

**Methods**

**Study Design and Patient Characteristics**

A retrospective analysis was conducted on the surgical treatment outcomes of 26 pediatric patients with spastic CP (quadriplegic). The cohort included 19 boys (73%) and 7 girls (27%), aged between 3 and 18 years (mean age 12.3 ± 0.9 years), hospitalized at the Federal Centre of Neurosurgery (Tyumen), Russia, from 2015 to 2023. This study was conducted in accordance with applicable guidelines and the Helsinki Declaration. Written informed consent for surgical intervention, data collection, and analysis was mandatorily obtained from the parents or primary guardians of all children in compliance with existing legislation.

**Selection Criteria**

Patient selection for surgical treatment was based on comprehensive assessments involving neurologists, rehabilitation specialists, orthopedists, and neurosurgeons. Study inclusion criteria were: 1) motor function level IV–V according to the Gross Motor Function Classification System (GMFCS), 2) spastic form of CP with pronounced muscle tone, 3) ineffectiveness of conservative therapy, and 4) ineffectiveness of botulinum toxin therapy. Exclusion criteria for RF rhizotomy included: 1) secondary muscle dystonia, 2) hyperkinetic syndrome, and 3) somatic contraindications. Mental development delay was not considered a contraindication for surgical treatment.

**Examination and Postoperative Monitoring**

Prior to surgery, all patients underwent brain MRI to evaluate hydrocephalus and rule out concurrent intracranial pathology, as well as CT and MRI of the lumbar spinal cord for surgical planning to exclude spinal canal pathology and assess the degree of spinal deformity. The assessment protocol included muscle tone evaluation using the modified Ashworth scale (MAS), evaluation of passive and active range of motion, gait video recording, and locomotor status evaluation using the Gross Motor Function Measure (GMFM)–88 scale. The MAS grades muscle tone from 0 to 4, in which 0 represents normal muscle tone and 4 signifies maximum tone, rendering passive movements completely impossible. For research purposes, muscle tone was assessed during assisted hip flexion and adduction, knee flexion and extension, and ankle dorsal and plantar flexion. The results of the spasticity level assessment were averaged across all studied muscle groups for subsequent comparison. The GMFM scale comprises 88 standard motor tests, each graded on a 3-point scale depending on the execution degree: 0 = no execution of movements, 1 = attempt to execute, 2 = partial execution, and 3 = full execution. The total scores are expressed as a percentage. Patients scoring 20% or less fall into the 5th category (most severe form of the disease), 20%–40% = the 4th category, 40%–60% = the 3rd category, 60%–80% = the 2nd category, and 80%–100% = the 1st category.

Subsequent observations and evaluation of patient status were conducted at intervals of 2–12 months postsurgery. All follow-up evaluations were performed by trained neurologists and rehabilitation specialists. Patient check-ups were performed in the outpatient clinic of the Federal Centre of Neurosurgery (Tyumen), Russia, on a scheduled basis from 1 month to annual examinations. The postoperative observation period ranged from 2 months to 5 years (mean 20.5 ± 2.8 months).

**Surgical Technique**

RF rhizotomy (ablation of spinal nerve roots) was performed by a single surgical team on all patients at levels L2–S1. Due to the significant pain associated with the procedure and the pediatric age of the patients, the intervention was conducted under general anesthesia with minimal muscle relaxation, typically using mask anesthesia. Preoperative medication with ketamine and benzodiazepines was administered intramuscularly by the anesthesiologist before transportation to the operating room. Upon arrival at the operating room, anesthesia induction, tracheal intubation, and artificial lung ventilation were performed. A Foley catheter was inserted, and anesthesia was main-
tained via infusion of propofol and fentanyl, monitored using a Bispectral Index monitor. Given that the operation was performed under neurophysiological monitoring, maintenance of an adequate anesthesia depth was crucial to obtain true neurophysiological responses. Muscle relaxants were used only during tracheal intubation. Electrodes for intraoperative myography were placed in the adductor muscles, hamstring group, quadriceps, gastrocnemius muscle, and anal sphincter. The ablation technique involved selective-guiding of the RF electrode to the spinal nerve root exit under fluoroscopic control (Fig. 1).

Electrodes were sequentially placed at L2–S1 levels bilaterally, typically at the intervertebral disc projection. For the S1 root ablation, the electrode was inserted up to the anterior edge of the sacrum through the S1 foramen. In cases of pronounced sciotic spinal deformity, conducting and localizing the electrode was challenging but not a fundamental obstacle to the procedure. Following electrode placement at the potential site of thermal effect, manual adjustment of the needle positioning was performed under fluoroscopic control using motor electrostimulation (4–8 Hz, stimulation amplitude 0.6 V) until the maximum motor effect was achieved, i.e., contraction of the muscle group innervated by the specific spinal nerve root. Additional motor responses were monitored using intraoperative EMG. After optimally positioning the electrode, thermal RF ablation of the selected root was performed at 70°C for 90 seconds. These parameters neither led to significant motor deficit nor restricted active movements in patients during the postoperative period. The procedure was performed using a G4 RF generator (Boston Scientific). At the onset of thermal ablation, with the correct positioning of the needle electrode, short-term (approximately 10- to 20-second) muscle fasciculations were observed in the involved muscle groups. The overall duration of the procedure ranged from 20 to 45 minutes using two channels of the RF destructor simultaneously and with adequate experience.

Statistical Analysis
Continuous variables are represented as mean ± SEM. To analyze significant differences between pre- and postoperative values of muscle tone and locomotor functions in different patient groups, depending on the type of data distribution, either the parametric t-test or the nonparametric Mann-Whitney U-test was applied. A p value < 0.05 was considered statistically significant. The collected data were analyzed using SPSS (version 24.0 for Windows, IBM Corp.).

Results
In 8 cases (30.8%), various surgical interventions for hydrocephalus had been previously performed, including endoscopic third ventriculostomy in 3 patients (11.5%) and ventriculoperitoneal shunting in 5 patients (19.2%). Atrophic changes in the brain cortex were detected in 61.5% of patients. In the studied cohort, only 1 patient was assessed as having mild cognitive impairments. Severe cognitive impairments were noted in 69.2% (n = 18) of the patients, while moderate cognitive deficits were found in 19.2% (n = 5) of the patients. The severity of cognitive deficits in the examined patients did not correlate with the degree of muscle tone impairment. However, a high correlation was observed between cognitive impairments and locomotor status as per the GMFM-88 scale (r = 0.70, p < 0.01). Five patients (19.2%) had a history of epileptic seizures. Scoliotic spinal deformity was observed in 23 patients (88.5%). Three patients had previously implanted baclofen pumps that had not been functioning for more than 6 months by the time of hospitalization. In 15 cases (57.7%), patients had previously undergone various orthopedic interventions for fixed contractures, including Achilles-tendon lengthening and hamstring group muscle-tendon lengthening. Prior to surgery, all patients had undergone multiple courses of conservative and rehabilitation treatment with minimal and transient clinical effects. Botulinum toxin therapy was administered in the spastic muscles of the lower limbs in all cases, with the most recent course being at least 6 months prior to the hospital admission.

Spasticity
Upon admission to the neurosurgical unit, the average level of spasticity in the lower-limb muscles was 3.0 ± 0.2 according to the MAS. Following lumbar spinal root RF ablation, a significant reduction in spasticity levels in the lower limbs was observed in all patients within the first hours after surgery. At discharge, which occurred 3–5 days postoperatively, the average spasticity level in all examined muscle groups significantly decreased to 1.14 ± 0.15 (p < 0.001). In the long-term postoperative period, there was a statistically significant tendency for pathological muscle tone recurrence; however, the spasticity level in the examined muscle groups remained consistently lower than the baseline level, averaging 1.49 ± 0.17 points on the MAS (p < 0.001 compared to baseline, p = 0.0416 compared to the early postoperative period; Fig. 2).

In 4 cases (15.4%), due to partial recurrence of spasticity, a repeat RF procedure was conducted after 4 and 12 months.

Motor Function
Despite the marked reduction of spasticity in the lower limbs, no significant change in locomotor status according to the GMFM-88 scale was observed in the patients

FIG. 1. Radiographic confirmation of RF electrode placement. Left: Anteroposterior view, electrodes implanted bilaterally at the L5 and S1 levels. Right: Lateral view.
with CP included in the study. In the long-term period, during the control examination of patients, the GMFM-88 level increased on average by 3.6% ± 1.4% (from 22.2% ± 3.1% to 25.8% ± 3.6%). Changes in GMFCS status were noted in 15.4% of patients, predominantly from GMFCS level IV to level III (Fig. 3). However, the average level of motor function per the GMFCS scale did not change significantly, shifting from 4.7 ± 0.1 to 4.5 ± 0.2. Given the study design, it is challenging to assess the contribution of spasticity reduction to the dynamics of the GMFCS.

**Complications**

No serious complications such as pelvic organ dysfunction, infectious complications, CSF leakage, and others commonly reported after invasive SDR were observed in the postoperative period. On average, 6.3 ± 0.2 days after surgery, 42.3% (n = 11) of cases reported pain syndrome and dysesthesia, manifested as itching and other unpleasant sensations in the lower limbs. Due to cognitive deficits or young age, it was impossible to determine the intensity of pain in most patients. However, in cases in which the patient could specify his or her severity, the average intensity of the pain syndrome on the visual analog scale was 4.1 ± 0.43 points. The mean duration of complaints of pain syndrome and dysesthesia was 3.5 ± 0.8 weeks. The pain syndrome was effectively managed by prescribing gabapentin or pregabalin.

**Discussion**

CP is the most common motor disorder in childhood, with a global prevalence estimated at 2–3 per 1000 live births.\(^1,4\) This condition encompasses a group of persistent disorders affecting movement and posture development, resulting from nonprogressive disturbances that occur in the developing fetal or infant brain.\(^1,5\) Neurological lesions in CP are heterogeneous, often including white matter damage, cortical/subcortical lesions, or developmental brain anomalies that disrupt motor control.\(^20,21\) CP is associated with various clinical manifestations including spasticity, dystonia, ataxia, and athetoid movements.\(^1,5\)

The pathological alteration of muscle tone in CP is characterized by a velocity-dependent increase in muscle tone and tendon jerks, representing heightened excitability of the tonic stretch reflex.\(^5\) This common motor disorder in CP disrupts motor function, leading to muscle/joint contractures, pain, and skeletal deformities.\(^2,3,5\) Currently, there is no universal method for effective treatment of this pathological condition. Conventional treatment of spasticity in children with CP remains challenging, despite the development of new therapeutic approaches. First-line spasticity treatments include physiotherapy, casting, oral medications (baclofen, benzodiazepines), botulinum toxin injections, and the implantation of devices for continuous intrathecal baclofen administration.\(^22,23\) However, these treatments have limited effectiveness in providing sustained tone reduction and functional improvement.\(^3\) Epidural electrical stimulation of the spinal cord has emerged as a promising technique, yet its efficacy continues to be studied.\(^24\)

Given the often unsatisfactory results of conservative spasticity reduction, particularly in patients with significant motor impairments, more invasive methods such as SDR are widely used.\(^7–10\) Despite advances in neurosurgical techniques and proven effectiveness in reducing spasticity, SDR remains a highly invasive surgical procedure involving laminectomy and selective irreversible destruction of spinal roots, leading to longer recovery times and higher risks compared with less invasive methods. Like any surgical operation, SDR carries a high risk of complications such as infection, bleeding, or nerve damage.\(^9–11\) Postoperative sensory disturbances or bladder dysfunctions are common, and patients usually require prolonged rehabilitation to maximize functional capabilities. These limitations stimulate the search for less invasive, safer, and equally effective treatment methods for spasticity in CP.
Given the limitations of existing treatment methods, there is interest in exploring alternative approaches such as RF ablation of peripheral nerves, spinal roots, and dorsal root ganglia (RF-DRG) for treating spasticity in CP.14,15 RF ablation is a recognized method for treating chronic pain syndromes, creating thermal damage to target nerves.25,26 RF destruction can be performed percutaneously through a small skin puncture, unlike traditional surgical rhizotomy that requires a multilevel laminectomy.11 The minimally invasive nature of RF ablation makes it an attractive option, especially in the pediatric population, where more aggressive interventions may carry greater risk. This method has shown promise in early research and clinical applications, offering potential benefits such as reduced muscle tone and improved pain control. In 1983, Turnbull published a study that included percutaneous lumbar rhizotomy in 21 patients with paraplegia, demonstrating initial success in reducing spams, particularly in patients with complete motor and sensory loss.13 In the same year, Herz et al. presented a study on 30 patients with quadriplegia and paraplegia suffering from intractable spasticity who underwent percutaneous RF foraminal rhizotomy. The procedure led to improved conditions in 94% of patients, with 73% achieving excellent results, and a complication rate of 3%.14 A year later, Kasdon and Lathi showed that 24 of 25 patients with severe posttraumatic spasticity after percutaneous RF rhizotomy reported positive results in reducing muscle tone and increasing the range of motion, maintained on average over 12 months.15 In 2003, a study led by Frèrebeau et al. assessed the efficacy of percutaneous sacral thermorhizotomy in 29 children with CP.16 The procedure showed positive results in improving spasticity and walking, classified as good in 9 cases and effective in 6 cases. Vles et al. conducted a pilot study on 17 patients with CP utilizing percutaneous RF lesions adjacent to the DRG (RF-DRG) to address severe hip flexor/adductor spasms.15 The study observed modest enhancements in muscle tone and reported improvements in quality of life from caregivers, indicating RF-DRG could be a potentially effective treatment for CP-related spasticity. In experimental conditions, Chang et al. demonstrated that pulsed RF ablation applied to the DRG of rats with spinal cord injury led to a significant and reversible reduction in spasticity.17 However, this reduction in spasticity in experimental animals was accompanied by a deterioration in locomotor function, indicating the need for caution when applying pulsed RF ablation in patients capable of movement. In 2023, Pascoal and colleagues applied percutaneous RF thermal neuroablation to treat spasticity of the adductor muscles and rectus femoris muscle in a 60-year-old patient with complete spastic paraplegia following a spinal stroke.18 One year after the procedure, the patient showed a significant reduction in spasticity, facilitating daily activities and care by assistants. Thus, the analysis of available publications shows that percutaneous RF ablation represents a promising method for treating spasticity associated with various neurological conditions including quadriplegia, paraplegia, myelopathy, and CP. Most studies demonstrated significant improvement in managing spasticity and alleviating symptoms, contributing to improved quality of life for patients. However, the importance of a cautious and individualized approach to the application of this method is also emphasized, considering possible side effects and the need for repeated procedures in some cases. Overall, these studies confirm the potential of RF ablation as an important tool in the comprehensive treatment of spastic disorders.

The RF ablation procedure involves insertion of an electrode under radioscopic control into the exit foramina of the target spinal roots, often at lumbar levels L2–S1, corresponding to the innervation of the lower limbs. The tip of the electrode is placed near the DRG; heating it to 70°C–80°C for 60–90 seconds leads to ablation of sensory fibers carrying afferent signals that cause spasticity. This creates partial sensory denervation to reduce hyperexcitability of the stretch reflex.5,8,14 Recent pilot studies and clinical experience have confirmed this mechanism. These studies have demonstrated the potential of RF-DRG ablation in alleviating pain and reducing muscle tone in patients with spasticity, including those with CP. Furthermore, it was noted that RF-DRG ablation has fewer side effects and complications compared with more invasive procedures. Despite promising results, most studies represent small case series without control groups.

Our study provides additional evidence for the use of RF ablation of spinal nerve roots to reduce muscle tone in children with severe spastic CP. In our study, we demonstrated statistically significant reduction in spasticity in patients with severe CP (GMFCS levels IV–V). No serious complications were identified in our study, and observed pain and dysesthesia are transient phenomena, effectively managed by prescribing medications for neuropathic pain syndrome. The performance of RF ablation of spinal nerve roots does not impose restrictions on the use of other invasive procedures for reducing spasticity and rehabilitation in the future, such as the implantation of systems for chronic epidural electrical stimulation of the spinal cord. The mechanisms of spasticity reduction in our study are associated with the fact that RF destruction of spinal nerve roots leads to disruption of afferent signals involved in the mechanisms of spasticity. This technique is minimally invasive and is typically performed transcutaneously under radioscopic guidance for placing electrode tips near ganglia or spinal roots at the lumbar level, corresponding to lower-limb innervation.13,15,26 Heating causes partial sensory denervation, reducing hyperexcitability of the stretch reflex and the corresponding muscle hypertonus. The advantages of RF ablation include the ability to perform minimally invasive bilateral treatment of multiple spinal levels simultaneously. This ability limits the risks of complications such as CSF leakage, infections, hematomas, and spinal deformities associated with methods of open surgical rhizotomy.8,11

Limitations of the Study

The presented study is limited by its retrospective design without a control group. Although the reduction in muscle tone was pronounced and sustained, the observed average increase in GMFM-88 scores by 3.6% and a slight improvement in the GMFCS level may have limited functional significance in this cohort with severe impairments. Further studies and longer-term data on the impact on
functionality and quality of life of patients with CP after spinal root RF ablation are needed. It is important to note that, while the initial results are encouraging, further studies and long-term research are needed to fully understand the efficacy and safety of RF destruction in treating CP spasticity. It will be crucial to continue research of this treatment method including exploring action mechanisms and long-term outcomes for determining its place in the spectrum of treatment options. As with any new treatment method, balancing potential benefits with understanding and mitigating possible risks will be key to its successful integration into clinical practice.

Conclusions

The findings of this study offer preliminary yet compelling evidence that RF ablation of spinal nerve roots can lead to a significant and enduring decrease in muscle tone among children with severe spastic CP. However, there remains a need for more extensive, controlled research to validate the long-term functional benefits, safety profile, and relative effectiveness of this technique compared with other existing invasive and noninvasive treatments for spasticity. Future research in this field is essential to ascertain the full potential and limitations of RF ablation as a therapeutic option for managing severe spasticity, ensuring that its integration into clinical practice is based on a comprehensive understanding of its efficacy and safety.

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References


Disclosures

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Author Contributions
Conception and design: AA Sufianov, Shapkin, Sufianova.
Acquisition of data: AA Sufianov, Shapkin, Iakimov, RA Sufianov. Analysis and interpretation of data: all authors. Drafting the article: Shapkin, RA Sufianov, Sufianova. Critically revising the article: all authors. Reviewed submitted version of manuscript: AA Sufianov, Shapkin, Iakimov. Approved the final version of the manuscript on behalf of all authors: AA Sufianov. Statistical analysis: Shapkin, Iakimov, RA Sufianov. Administrative/technical/material support: AA Sufianov. Study supervision: AA Sufianov, Sufianova.

Correspondence