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Peripheral Nerve

Combined Surgical Technique of Hyperselective and Partial Motor Neurectomies for Spastic Equinus, Equinovarus, and Claw Toe Deformities

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Background: Patients with spastic equinus, equinovarus, and claw toe deformities can experience marked pain and functional limitations in the ability to weight-bear comfortably, ambulate efficiently, or mobilize independently. Seen in 80% of patients with cerebral palsy and 18% of patients with stroke (1, 2), the spastic foot and ankle deformities, and its secondary sequelae of static joint contractures, osseous changes, and chronic pain, are unfortunately common.
Methods: Adult and pediatric patients undergoing combined hyperselective and selective partial motor neurectomies for varus or claw toe deformities were reviewed. Patient demographics and complications were recorded. Pre- and postoperative Modified Ashworth Scale scores were compared.
Results: Twenty-three patients (16 adults and seven pediatric) met inclusion criteria and were included in analysis. At early 6-month follow-up, the mean preoperative Modified Ashworth Score of 2.8 in adult patients and 3.0 in pediatric patients decreased to 0.6 postoperatively. Complications in three adult patients included one patient with temporary dysesthesias to the plantar foot, one with a popliteal abscess requiring incision and drainage, and one superficial wound dehiscence that was managed conservatively.
Conclusions: A combined technique of hyperselective and partial motor neurectomies are effective in decreasing tone in the correction of spastic foot and ankle deformities in both adult and pediatric patients in short-term 6-month follow-up.
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INTRODUCTION

The spastic equinovarus foot deformity is common and is seen in up to 80% of patients with cerebral palsy and 18% of patients with stroke.[1,2] Spasticity and overactivity of the gastrocnemius, soleus, posterior tibialis (PT), flexor hallucis longus (FHL), and flexor digitorum longus (FDL) muscles combined with weakness of the antagonist tibialis anterior, peroneus longus, and peroneus brevis muscles limit active ankle dorsiflexion and may preclude plantigrade ankle positioning. This results in gait disturbances, difficulties with weight-bearing, dependence on ankle-foot orthoses (AFOs), and limitations with positional transfers. Longstanding deformity can then lead to static muscle and joint contractures, secondary osseous changes, skin breakdown, and chronic pain.

Selective and partial neurectomies for the management of spasticity were originally described by Stoffel,[3] expanded upon by Brunelli and Brunelli,[4] and subsequently refined and termed "hyperselective neurectomies" (HSNs) by Leclercq and Gras.[5] HSN involves dissection of each branch of a motor nerve to its individual terminal motor rami as they coapt at the neuromuscular junction. At this level, 50%–70% of individual terminal motor rami are resected to complete the HSN.[6,7] This differs from partial motor neurectomy where segmental excision of individual motor fascicles are performed within a target motor nerve, for example, excising a segment of a posterior tibial nerve fascicle within the tibial nerve; and selective partial[8–10] motor neurectomy that involves excising fascicles within

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branches to a specific muscle after they have left the main trunk but before the terminal rami, for example excising one of two motor branches to the PT after it has branched from the tibial nerve (Fig. 1).[11] Partial motor neurectomy of the soleus, medial, and lateral gastrocnemius (MG and LG) muscles has previously been described for the surgical management of spastic foot deformities[12–14] and demonstrated to have long-term durable effects on improvements in gait and reduction in equinovarus deformities. However, a hyperselective approach, which has demonstrated durable intermediate-term results in the upper extremity,[15] has not previously been described for the lower extremity. This article outlines the clinical indications and surgical approach utilizing HSN of the medial and lateral gastrocnemius and soleus muscles to address equinus deformity, combined with partial motor neurectomy of the PT for varus foot deformity and of the FHL and FDL for claw toe deformities.

Takeaways

Question: The best surgical option for patients with spastic equinovarus and claw toe deformities secondary to upper motor injuries remains unknown.

Findings: This study presents a new surgical technique combining hyperselective neurectomies of the gastronemius and soleus muscles to address equinus deformity with partial motor neurectomies of the posterior tibialis, flexor hallucis longus, and flexor digitorum longus to address varus and claw toe deformities. Short-term follow-up in 23 patients undergoing this procedure demonstrated a postoperative Modified Ashworth Scale score of 0.6.

Meaning: At short-term follow-up, this novel combined technique is effective and resulted in a discernible reduction in spasticity in adult and pediatric patients.

METHODS

Surgical Technique

Surgery is performed under a general anesthetic, with the patient in the prone position with a sterile tourniquet on the upper thigh. Inhaled volatile anesthetics, neuromuscular paralytic agents, and spinal and peripheral nerve blocks should be avoided to allow for intraoperative nerve stimulation.

Hyperselective Neurectomy to Address Equinus Deformity

A 10- to 15-cm longitudinal incision is marked in the posterior midline in the lower leg, with the proximal extent ending at the popliteal crease (Fig. 2). In pediatric patients, a shorter incision can be utilized and in patients with anticipated difficult exposure or larger body habitus, a curvilinear lazy "S"-shaped incision extending from medial proximal to distal lateral can allow for a wider exposure. Skin flaps are elevated at the level of the fascia, which is then incised longitudinally in the midline using the lesser saphenous vein and sural nerve as a guide to the interval between the MG and LG.

The MG and LG are split in the midline, and this interval deepened (Fig. 3A). The plantaris muscle is identified and used as a guide to identify the soleus muscle, which lies just deep to it. Each motor branch to the MG, LG, and soleus is then carefully dissected intramuscularly to its terminal motor rami en route to the neuromotor endplates. At this level, individual fascicles are seen naturally arborizing without the need for interfascicular dissection. The MG branches are frequently closely intertwined with the medial sural artery and venae comitantes (Fig. 3B). Small perforators may need to be ligated to allow for adequate distal dissection and exposure. There are usually 1–2 motor branches to the MG, LG, and soleus, and each motor branch is marked with a vessel loop to ensure

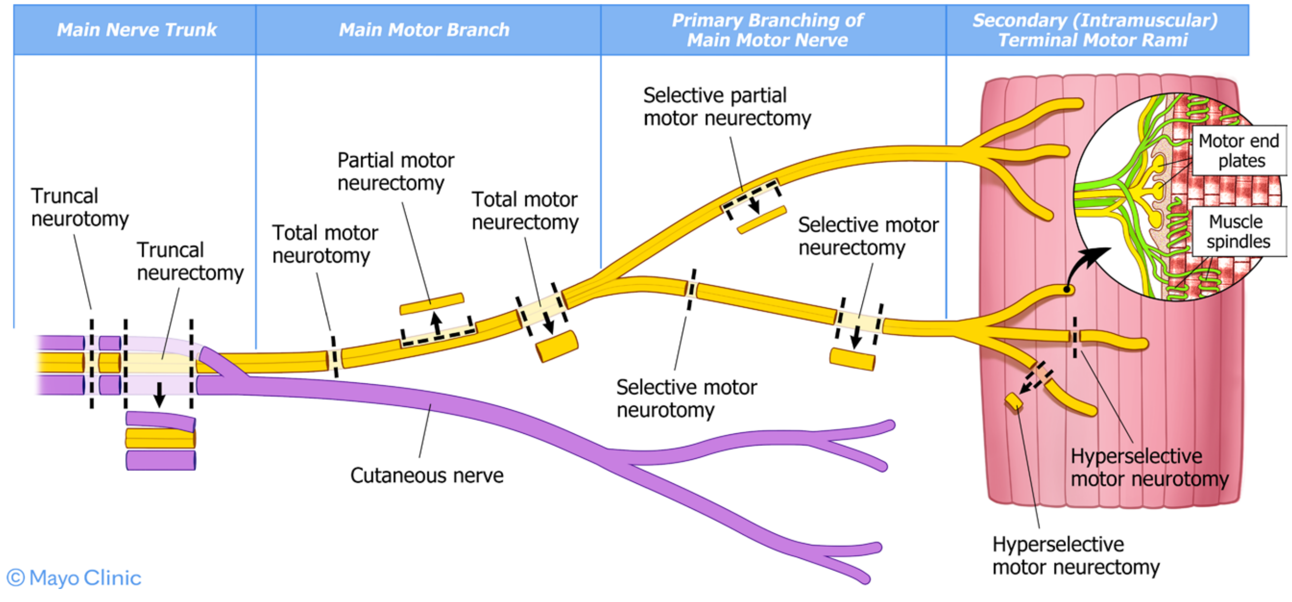

Fig. 1. Terminology of nerve-based procedures to address spasticity based on the level of nerve branching.

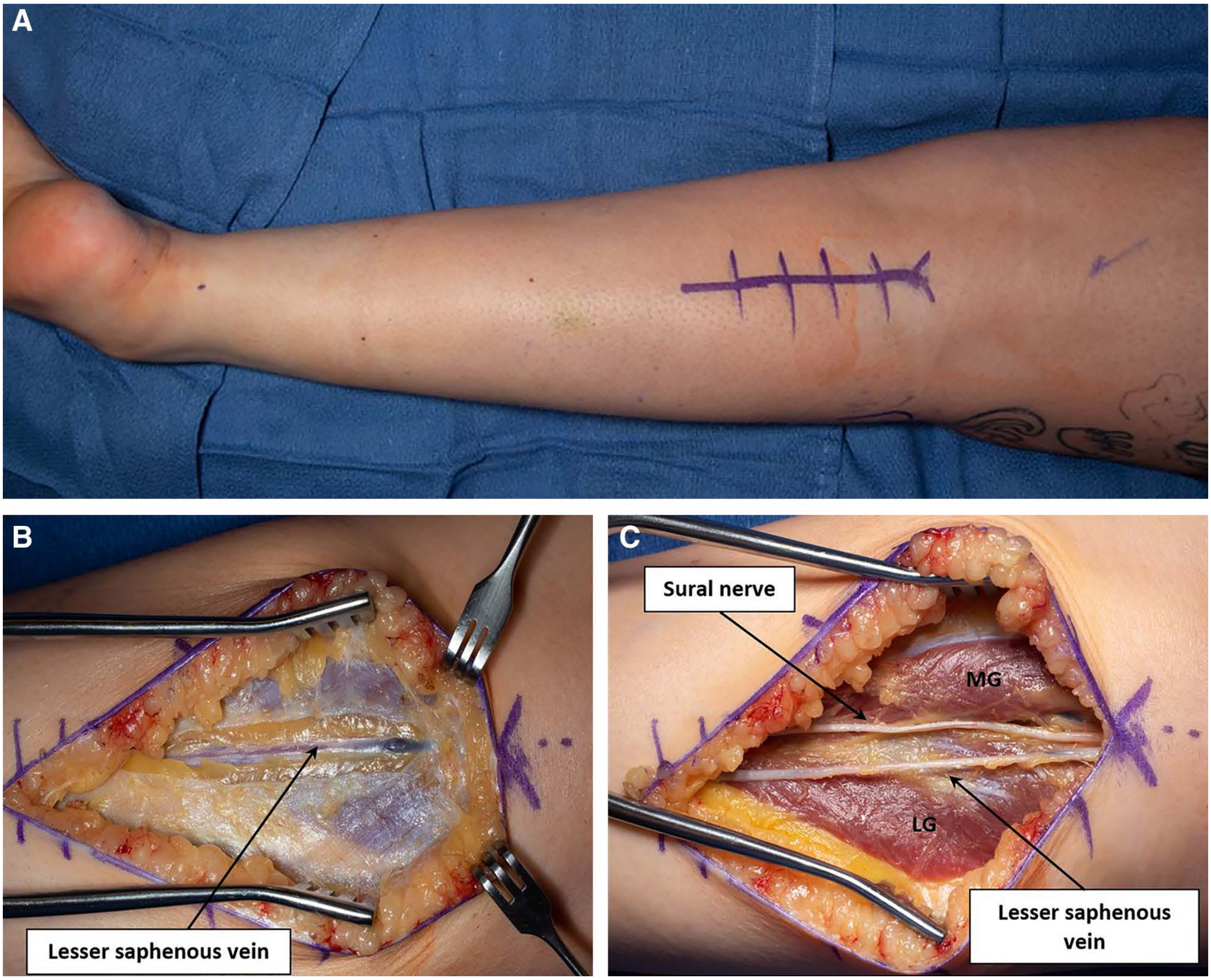

Fig. 2. Patient positioning and incision planning. The patient is positioned prone with the entire right lower extremity prepared with a tourniquet on the upper thigh. A 10-cm longitudinal posterior midline incision (A) is made in the lower leg and dissection carried down to the level of the gastrocnemius fascia. The lesser saphenous vein (B) and sural nerve (C) mark the midline interval between the MG and LG heads and are dissected circumferentially.

each is addressed sequentially (Fig. 3C). Branches of the terminal motor rami are confirmed with a nerve stimulator after the tourniquet has been release for at least 20 minutes to permit nerve reperfusion before stimulation. HSN is then performed with excision of approximately 70% of the terminal motor rami for each motor branch (Fig. 3D). A 1- to 2-cm segment of each terminal motor rami is neurectomized to prevent reinnervation of the muscles. This is then sequentially performed for the LG and soleus (Fig. 4).

Partial Motor Neurectomy to Address Hindfoot Varus and Claw Toe Deformity

If partial motor neurectomies of the PT, FDL, and FHL are required to address equinovarus or claw toe deformities, the tibial nerve is then further dissected distally to identify these motor branches (Fig. 5). There are usually 1–2 motor branches to the PT that branch off from the main tibial nerve within the distal portion of the incision (Fig. 5A). Partial motor neurectomy of the PT is typically performed at the tibial nerve level in lieu of distal dissection to the terminal motor rami, which would require more extensive intramuscular dissection through a much longer incision. However, if there is early branching of the PT fascicle from the main tibial trunk, then excision of 50%–70% of the visible branches within the incision can be performed in a selective partial motor neurectomy approach. The decision to perform either a partial motor or selective partial motor neurectomy of the PT is dependent on how proximal the PT branches leave the main trunk and ability to perform the neurectomy safely within the incision.

Intrafascicular dissection within the tibial nerve is then performed and a nerve stimulator used to identify the motor fascicles to FDL and FHL (Fig. 5B). The fascicle that produces maximal isolated activation of the target muscle is selected, and an approximately 1- to 2-cm segment of the isolated fascicle(s) is then excised to complete

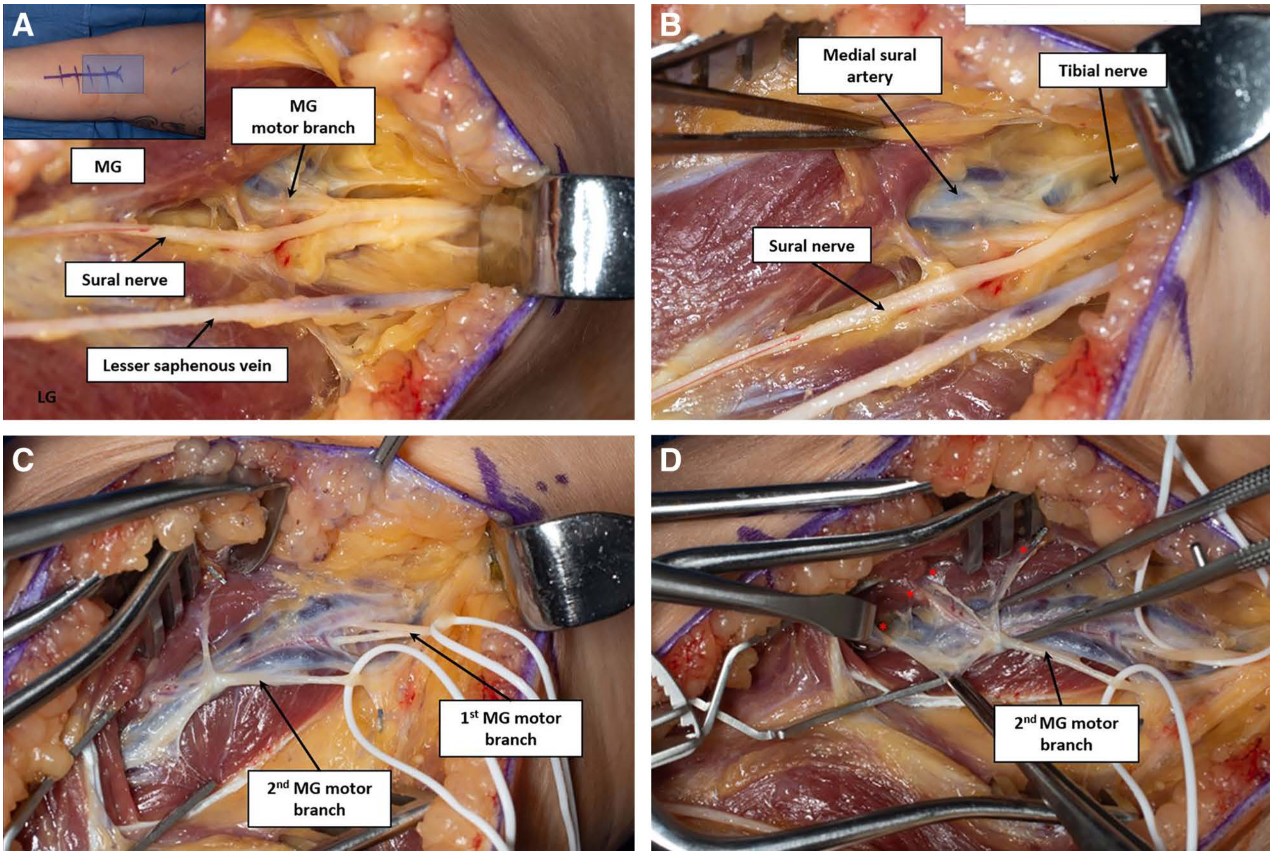

Fig. 3. Dissection and medial gastrocnemius hyperselective neurectomy. With the LG and MG split in the midline (A), deeper dissection is performed within this interval (B). C, Two motor branches to the medial gastrocnemius (white vessel loops) are seen intimately entwined with the medial sural artery. Each motor branch is traced distally until its terminal motor rami (D, red asterix) where hyperselective neurectomy and excision of 70% of the motor rami are performed.

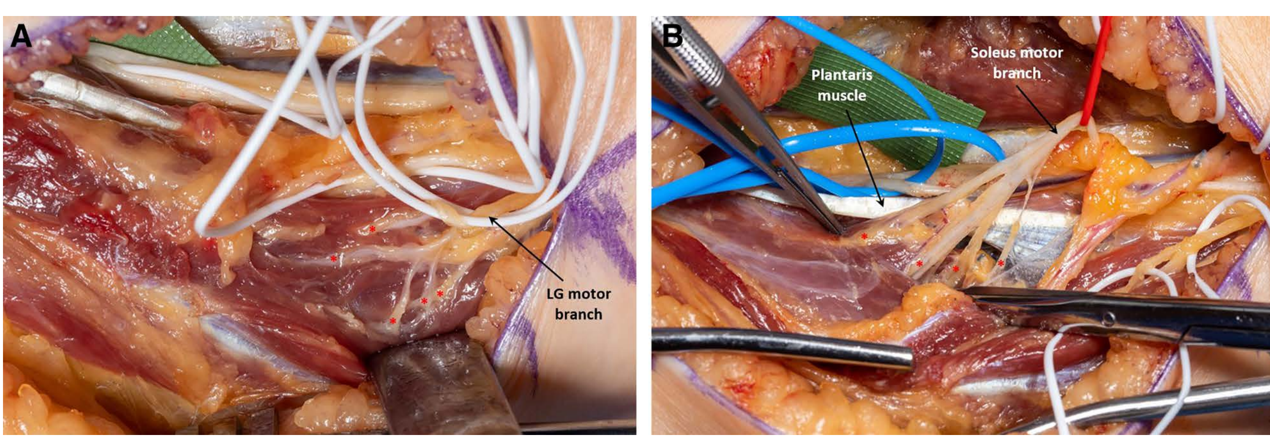

Fig. 4. LG and soleus hyperselective neurectomy. Distal dissection of the terminal motor rami (red asterix) of the LG (A) and soleus (B) motor branches.

the selective neurectomy (Fig. 5C, D). A soft-dressing and light compression wrap is kept on for 2 weeks postoperatively. Patients may weight bear as tolerated immediately but are advised to avoid running or heavy lifting. Although cautious return to use of an AFO brace is allowed, direct pressure over the surgical incision should be minimized. Patients are encouraged to maintain active and passive ankle range of motion and engaged in gait retraining once surgical incisions are healed.

Clinical Outcomes

Adult and pediatric patients undergoing this procedure to address spastic equinus, equinovarous, or claw toe deformities were retrospectively reviewed. Patient

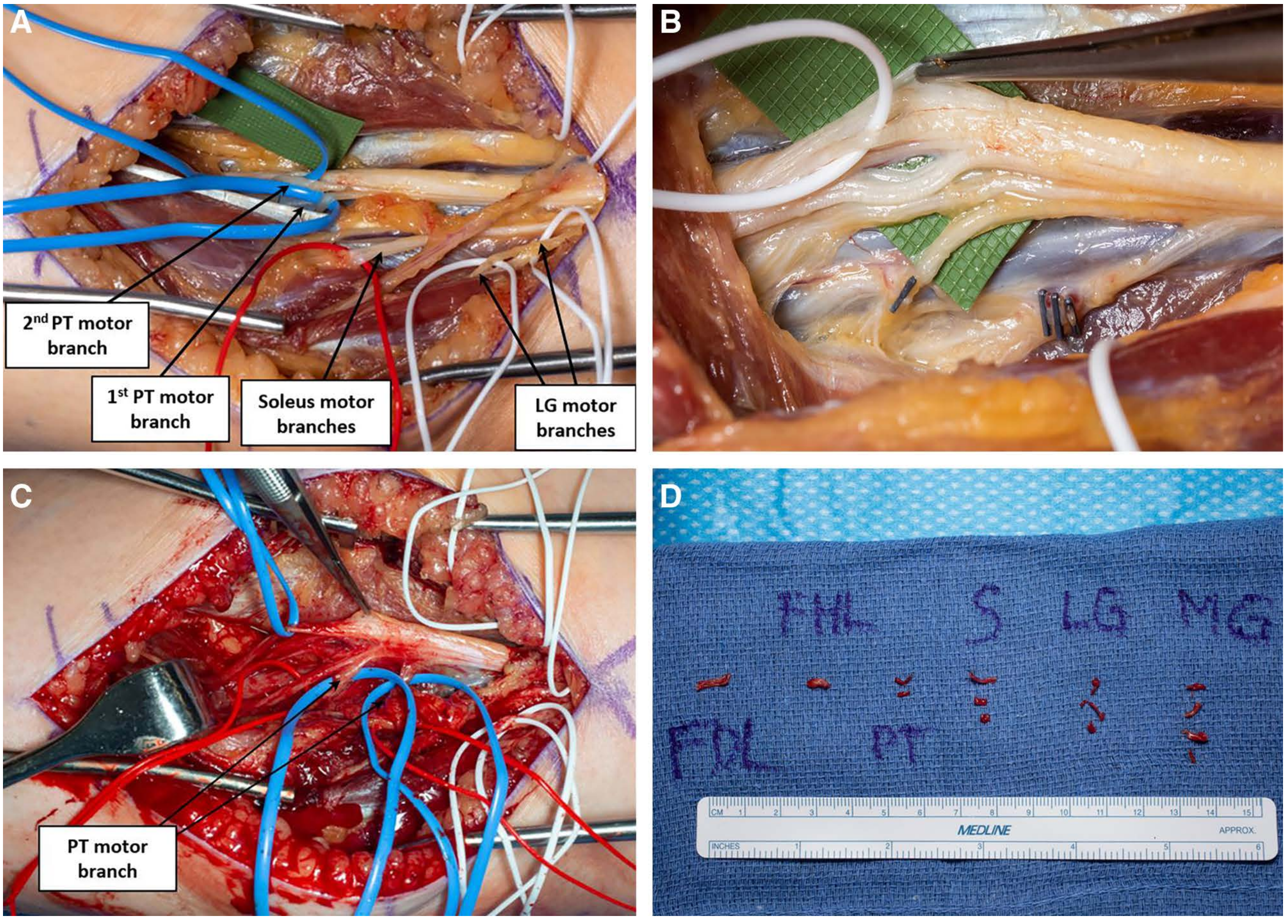

Fig. 5. Partial tibial motor neurectomy for equinovarus and claw toe deformities. Distal dissection of the tibial nerve and motor branches to the PT (A, blue vessel loop). Intrafascicular dissection within the tibial nerve (B) to identify the FHL and FDL fascicles (C). Excised neurectomy segments from hyperselective neurectomy of the MG, LG, and S and partial motor neurectomy of PT, FDL, and FHL (D). S, soleus.

demographics, time from diagnosis to surgery, and complications were recorded. Pre- and postoperative Modified Ashworth Scale (MAS) scores were compared. Patients without at least 6 months of follow-up were excluded.

RESULTS

Twenty-three patients undergoing this procedure from 2021 to 2023 at a single institution were included in this study. There were 16 adult patients (mean age of 44.3 years, six men, and 10 women) and seven pediatric patients (mean age of 10 years, five men, and two women). The most common cause of equinovarus deformity was cerebrovascular accident in adults and cerebral palsy in pediatric patients. For the adult cohort, this included patients undergoing HSN of the gastrocnemius and soleus alone (four patients) and those with combined procedures with additional partial and selective partial neurectomies for varus (10 patients) and/or claw toe deformities (10 patients). The pediatric cohort of patients all solely underwent HSN of the gastrocnemius and soleus alone. At early 6 months of follow-up (range 6–20 months), the mean postoperative MAS score was 0.6 in both cohorts, compared with a preoperative MAS score of 2.8 in adults and 3.0 in pediatric patients. Analyses of medium- and long-term outcomes, changes in gait pattern, and need for gait aids postoperatively are ongoing. There were complications in three adult patients, including one with temporary dysesthesias and sensory disturbance to the plantar foot that resolved over 3 months, one with a popliteal abscess requiring incision and drainage, and one with superficial wound dehiscence treated with conservative management.

DISCUSSION

The use of nerve-based procedures for the management of spasticity has continued to expand and evolve. The use of HSN in the upper extremity, especially for the treatment of spastic elbow flexors, has demonstrated durable and consistent results.[15] Both HSN and partial motor neurectomies only address the spastic component contributing to the equinovarus or claw toe deformities. Those patients with static contractures may require additional joint releases and other procedures to achieve a plantigrade ankle posture. We have applied this approach and combined gastrocnemius and soleus HSN with partial tibial motor neurectomies to address the spastic equinovarus ankle and associated foot deformities, with encouraging early results in both adult and pediatric patients. Ongoing follow-up and analysis of this patient cohort is necessary, given the possible delayed recurrence of spasticity due to the adoption phenomenon. This describes collateral sprouting from partially neurotomized motor nerves to reinnervate the adjacent denervated muscles resulting in recurrence.[5,16,17]

Considerations in Preoperative Assessment

A comprehensive preoperative assessment should include a detailed physical examination with documentation of passive and active range of motion, presence of clonus and joint contractures, and grading of spasticity using the MAS and/or Tardieu scale.[18,19] The Silverskiold test can be used to clinically identify patients with concomitant gastrocnemius contractures that may require additional muscle-tendon lengthening procedures. If ankle dorsiflexion is more restricted with the knee in extension compared with knee flexion, this is indicative of a positive test and the presence of gastrocnemius contracture.[20]

The effects of an ultrasound-guided temporary tibial nerve blockade can help in differentiating between the contributory effects of spasticity versus contractures. A patient's prior response to phenol or botulinum toxin injection can aid in predicting the potential expected postoperative outcomes. Dynamic electromyography studies and gait analysis can identify co-contraction of agonist and antagonist muscles, the presence of volitional electrical activity, and changes in gait patterning.

Multidisciplinary Team Approach

Patients should also be assessed by a multidisciplinary team including physical medicine and rehabilitation, pediatric/foot, and ankle orthopedic surgeons to ensure all nonoperative measures have been exhausted and for comprehensive surgical planning, respectively. Nonoperative options include exercise therapy, physiotherapy, use of an AFO, antispasmodic medication (baclofen, tizanidine, and diazepam), and chemical denervation. Phenol neurolysis and motor point blockade are avoided, if possible, due to the local tissue effects and induced scarring that can make subsequent surgery more difficult.

Multidisciplinary discussion is crucial for preoperative planning. For example, if a patient may benefit from a PT tendon transfer for ankle dorsiflexion, then PT partial motor neurectomy should be deferred to preserve this option. Patients with fixed varus deformities and contractures may benefit from posteromedial ankle release and split anterior tibialis transfer or complete PT transfer, whereas those with spasticity alone may benefit from a selective neurectomy approach. Indications for MG, LG, and soleus HSN include both adult and pediatric patients with volitional lower extremity motor control but spastic equinus deformity causing issues such as toe walking, knee recurvatum, circumduction gait, early fatigue, inability to walk long distances, pressure wounds with footwear, and significant pain. The goal of surgery is to improve functional ability and smoother ambulation. In patients who lack volitional lower extremity control, indications for surgery include difficulty with positional transfers, standing ability, and significant pain. The goal of surgery, in these patients, is to achieve pain-free plantigrade dorsiflexion to facilitate ease of activities of daily living.

The addition of partial motor neurectomy of the PT is indicated in patients with equinovarus foot deformity, and FHL and FDL neurectomies for patients with concomitant spasticity in the toe flexors. Typically, these nerve-based procedures are performed before any contracture releases or muscle-tendon lengthening procedures.

CONCLUSIONS

This combined technique of gastrocnemius and soleus HSN and PT, FHL, and FDL partial motor neurectomies is a reproducible method to address spastic equinus, equinovarus, and claw toe deformities with noticeable reduction in spasticity that was maintained 6 months postoperatively. Through a single incision, the surgeon can tailor the procedure according to the patients' specific clinical presentation and goals of surgery. This technique expands the toolbox of nerve-based procedures to include HSN for addressing spasticity in the lower extremity. A multidisciplinary team approach including physical medicine and rehabilitation; pediatric neurology; and hand/peripheral nerve, pediatric orthopedic, and foot and ankle surgeons is crucial to formulating a comprehensive management plan.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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