Revisional Peripheral Nerve Surgery

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There are variety of peripheral nerve disorders that exist in the foot and ankle. Some of the common conditions can be categorized as neuroma, compressive neuropathies, and diabetic neuropathy.

**NEUROMA**

Originally described in 1845,\(^1\) neuroma describes a painful condition of the common plantar nerves of the interspace of the forefoot. Although the term “neuroma” is popularly used to define the condition, other terms, such as “neuralgia,” “neurtitis,” “perineural fibrosis,” and “interdigital neuritis” have been used to describe the condition as well.\(^1–5\) Neuromas secondary to trauma have also been reported.\(^6\)

**Compressive Neuropathies**

Patients with compressive neuropathies commonly present with diffuse pain secondary to nerve compression or entrapment within a tunnel or fibro-osseous space.\(^7\) One of the more common entrapment/compressive neuropathies is tarsal tunnel syndrome (TTS), which is compression of the tibial nerve within the tarsal canal behind the medial malleolus.\(^8\) Other compressive neuropathies have been reported within the foot and ankle, such as the deep peroneal nerve\(^9\) as it travels with the dorsalis pedis artery beneath the inferior extensor retinaculum in the anterior aspect of the ankle and at the dorsal midfoot. Sural and saphenous nerves have been reported to be compressed along their course as well.\(^10\)

In patients with long-standing heel pain, entrapment of the first branch of the lateral plantar nerve, also called “Baxter’s nerve,” may occur as it travels between the abductor hallucis muscle and quadratus plantae muscle.\(^11,12\)

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Diabetic Neuropathy

Introduced by Dellon, the theory of diabetic neuropathy is based on external nerve compression interrupting axonal blood flow. Release of the peripheral nerve compression sites is believed to restore axonal blood flow, relieve pain, and restore sensation. Although it has shown clinical promise based on previous studies, this procedure has not been widely accepted as a standard treatment for diabetic neuropathy.

Nerve disorders can cause pathologic problems, such as loss of sensation, loss of motor function, pain, autonomic changes, and other various symptoms. A variety of operative techniques are employed to relieve patients’ symptoms. However, when these techniques fail to provide relief, chronic pain can persist, creating hindrances in the daily lifestyle of the patient. Reports have shown it is not uncommon for poor outcomes to arise with peripheral nerve surgery and create chronic symptoms for the patient. The clinician must identify factors associated with direct causes of chronic nerve pain. These factors can be categorized as internal or external factors. Internal factors (ie, nerve damage secondary to injury or trauma, myelin degeneration, axon damage) are related to changes within the nerve tissue that contribute to patients’ symptoms, while external factors are the outside contributions (ie, biomechanical factors, space occupying lesion, narrow fibro-osseus tunnel), which create chronic nerve disorders. Internal factors that affect peripheral nerves create symptoms that either include spontaneous discharges of the nerve that eliciting severe pain, known as ectopic neuralgia, or can generate severe pain on palpation or activity, known as nociceptive neuralgia.

In evaluating external factors, nerve compression anywhere along the course of the peripheral nerves may cause symptoms in the lower extremities. These sites include the common peroneal nerve at the fibular neck, the posterior tibial nerve at the medial ankle and the posterior tibial nerve bifurcation site at the abductor hiatus, the deep peroneal nerve at the dorsal midfoot, and the superficial peroneal nerve at the anterolateral leg. A positive clinical finding of nerve irritation or compression is noted by the presence of a Tinel’s sign on percussion of the nerve at the compression site. A positive Tinel’s sign is consistent with nerve pathology and may reveal current disease to the nerve, a narrow fibro-osseus tunnel, or a systemic disease state contributing to the nerve condition. The sensation of the peripheral nerve course along with the lumbar and sacral dermatomal distribution should be analyzed. A loss or decrease in sensation in the anatomic region of a peripheral nerve root should lead to the suspicion of lumbar nerve root pathology. It is important that they not only be recognized but a distinction be made between the two types of factors.

An often-overlooked common external factor is double crush syndrome. Double crush syndrome occurs when a patient has a proximal nerve compression that alters axonal transport and may contribute to a secondary distal entrapment. Double crush syndrome was originally described by Upton and McComas, who observed that 70% of their patients who had symptomatic carpal tunnel and ulnar neuropathy had evidence of cervical root lesions. They believed that there was an increased association of symptomatic patients and those with proximal constraints and metabolic abnormalities, such as diabetes. As a result, the patient experiences decreased axoplasmic flow, which predisposes the nerve to dysfunction. These compressions are thought to compromise nerve function by altering the axonal transport delivery system, which is critical to nerve function. If unrecognized, patients undergoing surgical release of a peripheral nerve entrapment may only have mild or transient relief of the presenting symptoms.
When evaluating a patient for chronic neurologic pain, a comprehensive evaluation must be undertaken to provide insight as to why the primary surgical correction was unsuccessful. Factors to be considered include identification of the specific nerve involved and review of prior nonoperative and operative intervention. Important questions that must be answered during the evaluation are:

- Are there any systemic diseases associated with the patient’s condition?
- Does the patient have an underlying biomechanical factor associated with the chronic pain?
- Did the patient have any contributions from previous trauma to the area that may contribute to the symptoms?
- Was the initial diagnosis of the patient’s symptoms correct?
- Is there a difference between the initial and current symptoms experienced by the patient?
- Did the patient experience any resolution of initial symptoms, whether it was full, partial, or not at all?

A thorough evaluation, including physical examination, imaging, laboratory, and electrodiagnostic studies is necessary to assure the proper diagnosis before intervention. It is common for the surgeon to obtain a limited evaluation and testing of the patient before performing repeat surgery. The characteristics involving the nerve pain must be identified through a complete foot, ankle, and lower extremity examination. Patients with chronic peripheral neuropathy symptoms will commonly present with complaints of intermittent burning-type pain, numbness, and paresthesias, which is initially generalized and vague. This symptomatology may be localized to the distribution of the peripheral nerve or multiple nerves. Pain from a compression neuropathy is commonly accentuated by activity and worsens at the end of the day. As the compression progresses, night pain may manifest and is thought to represent nocturnal ischemia.

In the neurologic examination, testing should begin with the origin of the peripheral nerves at the lumbar spine. The location of the nerve symptoms may not be related to local nerve pathology within the foot or ankle. Pathology of the lower back with lumbar nerve root compression because of a herniated disc may be the primary etiology of symptoms in the feet or toes, regardless of the presence of symptoms in the lower back. Lumbar nerve root compression in the lumbar spine can be assessed with either a straight leg-raise test or a slump test. The slump test is a reliable indicator in the diagnosis of lumbar nerve root impingement. The slump test is a modification of the straight leg-raise test and is performed in the seated position. It is a progressive series of maneuvers designed to place the sciatic nerve roots under increasing tension. Patients with a positive test will require further evaluation by a physician trained in the treatment of spinal disorders.

Clinical examination may reveal hypoesthesia to pin-prick and light touch may be appreciated. Percussion of the peripheral nerve at a site of compression may elicit paresthesias in the distribution of the injured nerve (Tinel’s sign). Occasionally, in more advanced cases, nerve trunk tenderness to direct pressure with proximal and distal radiation of symptoms (Valleix’s Sign) may be elicited. In the diagnosis of TTS, the use of a venous tourniquet may assist in the diagnosis of venous congestion as an etiologic factor in the pathogenesis. Other investigators have proposed
biomechanical mechanisms to the symptoms of TTS, with the recreation of pain with inversion and eversion of the foot.\textsuperscript{20} As the compression of the tarsal tunnel continues, motor weakness of the intrinsics may occur. Loss of the intrinsics may be tested by having the patient fan their toes apart or by the presentation of multiple contraction of the digits.

There are many biomechanical and joint conditions of the lower extremity that may aggravate adjacent nerves, so it is imperative to perform a thorough biomechanical assessment to include range-of-motion, manual muscle testing, palpation of joints, and a static weight-bearing and gait examination. Abnormalities of the biomechanical examination should be addressed with the use of orthotics, braces, or supportive shoes as necessary. Tests that can be performed include radiologic studies, electrodiagnostic studies, and peripheral nerve blocks. Radiologic studies are helpful to diagnose biomechanical effects on nerve pathology, along with any bone abnormalities, fractures, or external space-occupying lesions. Weight-bearing foot and ankle radiographs are helpful to evaluate the presence of joint arthrosis, biomechanical abnormalities, or bone prominences as a primary source of the patient’s symptoms or by contributing to peripheral nerve compression.

Electrodiagnostic studies can be helpful in determining the quality of the nerve being examined, along with determining the presence of active pathology to the nerve. Nerve conduction studies (motor, sensory, or mixed) evaluate the function of a particular nerve by electrically stimulating the nerve.\textsuperscript{21} The clinical response is compared with normative data, based on the specific nerve at a specific site. This test can yield useful information about axonal loss and demyelination.\textsuperscript{21} The nerve conduction velocity is determined by dividing the distance by the conduction time (latency). External neural pressure initially results in focal demyelination. The degree of nerve conduction velocity slowing and the presence of secondary axonal changes are helpful in grading the severity of the nerve compression.\textsuperscript{21} These studies have been reported to have questionable impact on the type of revisional procedure that is performed.\textsuperscript{22}

It is important for the clinician to read studies in light of the full examination and not rely solely on the results from electrodiagnostic studies, because of incidence of false-negatives. Budek and colleagues\textsuperscript{23} performed nerve conduction studies on 28 patients with pes planus. The results demonstrated mild-prolongation distal latency of the medial- and lateral-planter sensory nerves, and delayed sensory conduction velocity of the medial-planter sensory nerve. The presence of electrodiagnostic abnormalities in this study population helps to substantiate the presence of compression neuropathy of the medial- or lateral-planter nerve in pes planus subjects. Bailie and Kelikan, over a 10-year period, examined 47 patients who underwent surgical management for TTS.\textsuperscript{24} All patients had nonsurgical care for an average of 16 months before surgery. The symptom triad of pain, paresthesias, and numbness was the most common clinical presentation. All had a positive Tinel’s sign and nerve compression test at the tarsal tunnel; however, electrodiagnostic studies were abnormal in only 38 feet (81%).

A nerve block provides insight on the degree of nerve damage, which may be present in the patient by isolating the nerve. The use of a local anesthetic (lidocaine or bupivacaine) diagnostic block can help determine whether revision transection of the nerve or specific nerve branches could be successful in eliminating pain.\textsuperscript{25} An additional test that has been reported to provide a sensory test of peripheral nerve function is a Pressure Sensory Specific Device (PSSD).\textsuperscript{26} Although there have been limited studies reported, the PSSD is designed to measure one-point and two-point sensory pressure thresholds and two-point minimum space thresholds.
REVISON SURGERY TREATMENTS

The primary reason for revisional surgery is inadequate nerve release in the primary procedure. Careful attention must be directed at the incision site of the original procedure, as well as obtaining pertinent clinical and surgical reports of the patient’s care. The surgical description is very important to determine if adequate exposure or decompression was performed during the primary surgical procedure. This could also be important to determine if there is any hyperpathia or dysesthesia present along the incision and along the course of the nerve.

Assuming the correct diagnosis was made, the next predictor of a successful outcome is the correct performance of the surgical procedure. If the procedure fails to completely address the external compression, creating the neuropathic symptoms in entrapment neuropathies or adequately resect stump neuromas, these procedures may provide either partial or no relief. Proper surgical technique addresses superficial and deep fascial structures, narrow fibroosseus tunnels, and tendon coursing over the nerves. These are important structures which require complete release.

Pathologic changes induced by nerve adhesions must also be considered in revisional situations. Degenerative changes or scarring of the nerve bed may occur because of trauma, surgery, repetitive motion, or systemic diseases, such as diabetes or rheumatoid arthritis. These changes disrupt the gliding moment of the nerve and create neuro-fibrosis. Reduction of the intraneural blood flow from such scarring surrounding intraneural vessels causes ischemic changes in interfascicular tissue. The nerves become less elastic and more vulnerable to pressure.

When treating peripheral nerve pathology, consideration must be given to the unique anatomy of nerve movement. Loss of the gliding function is critical to provide the most optimal outcome in revisional nerve surgery. In peripheral nerve surgery, the formation of scar tissue is detrimental and if the nerve is inadequately released, it will limit the extent of the patient’s recovery and pain relief. The nerve’s gliding function is paramount to preventing adhesions to the surrounding tissue postoperatively. The paraneurium, as described by Millesi, contains special gliding tissue, which allows easy dissection and mobilization of a nerve. When the gliding apparatus is lost the nerve becomes adherent to its surroundings.

The environment of a bloodless field and the use of magnification, bipolar coagulation, and intraoperative electrical stimulation of the nerve provide optimal intraoperative conditions during revisional nerve surgery. When evaluating the quality of the nerve intraoperatively, Fontana’s bands can help to determine the health of the peripheral nerve. In 1779, Felice Fontana described what appeared to be spiral bands surrounding peripheral nerves. These bands have been considered as representing nerve fiber undulation and can be seen readily through the epineurium as healthy nerve. Dellon observed that Fontana’s bands could not be seen when the median nerve was inspected during carpal tunnel decompression, while the bands often returned following intraneural neurolysis. Research performed by Abe colleagues in experimental peripheral nerve adhesion in rabbits confirms that the disappearance of Fontana’s bands appears to be a fairly reliable indicator of nerve fibrosis. Numerous causes have been described creating fibrosis of peripheral nerves following surgery, such as external compression, edema, hematoma, and ischemia.

Neurolysis

Common surgical options for treatment of compression neuropathies in the foot and ankle include decompression or external neurolysis at the site of entrapment and, infrequently, internal neurolysis. When performing neurolysis on a nerve densely
adherent to surrounding structures, one must ensure that longitudinal excursion will be restored postoperatively. If the local environment remains unaltered, adhesions will recur and clinical symptoms are likely to persist or return. The success rates of primary neurolysis surgery in compressive neuropathies has been well documented. However, when primary neurolysis does not yield success, there are circumstances when revision nerve surgery in the form of a secondary neurolysis needs to be performed. The results from surgical correction from this condition vary in the tibial nerve,\textsuperscript{33–37} deep peroneal nerve,\textsuperscript{38} and first branch of the lateral plantar nerve.\textsuperscript{39} When failure presents, the patient’s symptoms may show no improvement, partial improvement, or temporary improvement for a short period of time.\textsuperscript{40}

With compression neuropathies, incomplete decompression of the bone or soft tissue that is creating impingement is one of major cause of recurrence. Thus, addressing malunions, bony prominences, bony fragments, fascial or soft tissue impingement, and incomplete releases of previously treated entrapment syndromes should yield a beneficial outcome.\textsuperscript{22} However, this will not yield the best results if the integrity of the nerve is compromised.

\textit{Revision TTS}

When performing revisional nerve surgery in the tarsal tunnel, it is important to perform release of the all nerves of the tarsal tunnel, even if they were not all previously released in the primary surgery. They include the posterior tibial nerve, medial plantar nerve, lateral plantar nerve, and medial calcaneal nerve. The medial and lateral plantar nerves need to be released at the flexor retinaculum fascia of the abductor hallucis. The medial and lateral plantar nerve fascial septum is excised and the medial calcaneal nerve tunnel is released as described by Barker colleagues.\textsuperscript{41} Raikin and Mannich\textsuperscript{40} identified factors that impact on the success of tarsal tunnel surgery, which include incorrect diagnosis, adhesive neuritis, intraneural damage, and double crush syndrome. Incomplete release of compressive structures or adhesions during the postoperative course can cause symptoms to persist. When performing a revisional neurolysis in the presence of incomplete release, it is important to release the posterior tibial nerve while identifying the point of compression that was unreleased. In the presence of adhesions secondary to the postoperative period, other options to prevent the nerve from being adhered after the revision surgery are discussed with nerve wrapping and grafting.

Numerous reports have shown poor outcomes related to inadequate initial release of patients with TTS.\textsuperscript{29,32,40} Poor results with revisional surgery have been seen with patients with radiculopathy or with systemic disease. Revisional surgery has been recommended to avoid surgical decompression in patients with connective tissue disease, as they may have subclinical neuropathy.\textsuperscript{40} Kaplan and Kernahan\textsuperscript{42} operated on one patient without symptom relief after tarsal tunnel surgery. The revision procedure was extended decompression distally into the sole of the foot, and the patient had complete symptom relief (Evidence-Based Medicine or EBM Level IV). Zeiss and colleagues\textsuperscript{43} discovered in reoperation of two patients, after initial tarsal tunnel compression release, that incomplete release of the flexor retinaculum can lead to recurrence of symptoms (EBM Level IV). Eberhard and Millesi\textsuperscript{44} operated on two patients who had two, and one patient who had seven, previous surgeries for TTS (EBM Level IV). The procedures used included the removal of the abductor hallucis muscle or its fascia; however, none of the patients experienced relief of their symptoms. Pfeiffer and Cracchiolo\textsuperscript{45} operated on six patients with previous tarsal tunnel surgeries. Four had one previous tarsal tunnel operation, one had two, and one had four previous operations. Procedure involved the dissection of the tibial nerve, and the deep
abductor hallucis fascia was divided over the medial plantar nerve. Novotny and colleagues\textsuperscript{46} found results of 100\% with release of posterior tibial nerve and its branches, and coverage with radial free forearm flap (EBM Level V). Zahari\textsuperscript{47} also had complete resolution of symptoms after re-exploration of the posterior tibial nerve with release from scar tissue (EBM level V). Skalley colleagues\textsuperscript{32} evaluated three groups of revision tarsal tunnel surgery patients. Patients who had no significant scarring and inadequate release of the posterior tibial nerve did much better postoperatively than patients who had scarring with adequate release or patients who had both scarring and inadequate release (EBM Level IV). Gould initially reported the use of the procedure in the foot and ankle with 63\% good or excellent results with the vein wrap procedure; however, 25\% of patients experienced worsening of their symptoms.\textsuperscript{48} Barker and colleagues\textsuperscript{41} reported revisional peripheral nerve surgery in 44 patients who had previous tarsal tunnel surgery by performing neurolysis of the posterior tibial nerve, medial plantar nerve, lateral plantar nerve, and calcaneal nerves. The patients had a mean follow-up of 2.2 years and outcome results showed 54\% were excellent and 24\% were good.

**Revisional neuroma excision**

In the planning of the revisional plantar neurectomy, a plantar incision is recommended. This will allow tracing of the branch of the common digital nerve off of the medial-plantar or lateral-plantar nerve distally to the site of the stump neuroma formation. This will allow for adequate length of the nerve to resect and bury into the intrinsic musculature of the foot.\textsuperscript{49–52} Some investigators advocate re-exploration of the interspace where the previous surgery was performed.\textsuperscript{50,53} Beskin and Baxter evaluated two surgical techniques that were used to resect the nerve over a 2.5-year period, using either the previous dorsal incision or a transverse-plantar incision proximal to the metatarsal heads.\textsuperscript{53} Overall results revealed significant improvement for greater than 80\% of patients after their final operation (EBM Level IV). Johnson and colleagues\textsuperscript{50} re-explored 39 patients with recurrent interdigital neuroma. Of these, 33 patients received a longitudinal plantar incision and four received a dorsal incision (EBM-Level IV). The investigators found 22 patients obtained complete relief or marked improvement in pain. The success rates of these revision surgeries reported higher success rates than previously published studies. Stamatis and Myerson retrospectively reviewed 49 patients, where re-exploration through a dorsal approach and nerve transaction at the proximal site was performed in 60 interspaces for recurrence or persistent symptoms\textsuperscript{54} (EBM-Level IV). Based on their study, Stamatis and Myerson found high dissatisfaction rates with their approach for revision surgery similar to other reported re-exploration revision surgeries.

Reported complications associated with primary surgical intervention for neuromas (nerve resection, neurolysis) include but are not limited to dead space hematoma, numbness, stump neuroma, residual pain, contracted digits, and inadequate resection of the nerve.\textsuperscript{55} The rates of residual symptoms reported after primary excision for neuroma surgery can be as very high.\textsuperscript{56} One of most common complications reported is persistent symptoms after primary excision of interdigital neuroma, where the patient continues to experience the original pain before surgical correction. In a retrospective review of primary resection of interdigital neuromas by Coughlin and colleagues, 26 of 81 patients reported residual pain at final follow-up, along with scar sensitivity, and shoe and activity modification.\textsuperscript{55}

**Revison superficial peroneal nerve**

Chiodo and Miller\textsuperscript{6} compared 27 consecutive patients with superficial peroneal neuroma in two different groups: one group with transection and burial of the proximal peroneal
nerve stump into muscle and the other group with transection and burial of the proximal stump into bone (EBM level IV). In the group with transection of the superficial peroneal neuroma and burial into muscle, 4 out of 16 patients required revisional surgery because of recurrent neuropathic symptoms. All four had proximal resection with burial into bone. The average perceived relief of pain improving was 79%. These patients had less pain, especially on the skin of the anterolateral leg, but still had some residual deep pain. In the group with transection and burial of proximal stump into bone, no patients required revision surgery because of recurrent neuropathic symptoms.

**Diabetic neuropathy**

The results of peripheral nerve release are encouraging and rates of revisional surgery have yet to be reported. There are numerous reports published in the literature that show the positive results of using this procedure. However, most of the studies that have been published have questionable research designs and are evidence-based level IV studies. Future quality studies (evidence-based level I or II) are needed before this procedure becomes more widely accepted among foot and ankle surgeons. The discussions about the surgical treatment of diabetic peripheral neuropathy has led to an improved understanding and dialog about the treatment of peripheral nerve disorders in diabetic and nondiabetic patients.

**Nerve Wrapping**

Originally described in the upper extremity, the procedure of nerve wrapping has been expanded for use in the lower-extremity revision nerve surgery. The goal of performing this procedure with revision neurolysis is to provide a barrier, by using an autogenous harvested vein, designed to protect a nerve from external compromise, relieve symptoms, and improve function in patients with adhesive neuralgia. The veins that have been reported are glutaldehyde-preserved umbilical veins in the upper extremity and autogenous saphenous veins. Based on a case report, histologic studies after 17 months postoperatively in a patient who underwent this procedure revealed vein graft tissue in direct apposition to the nerve, with no fibrous scarring within or around the nerve. This procedure is commonly performed in conjunction with a neurolysis procedure, which releases the nerve at the site of scarring. Although other forms of protecting the nerve are available, ultimate success of this procedure depends on the integrity of the nerve itself.

Schon and colleagues retrospectively reviewed and found mixed results in patients who were provided revision nerve release with vein wrapping from the saphenous or umbilical vein, for 58 patients who had chronic pain after previous nerve release (EBM Level IV).

**Nerve Grafts**

Free nerve grafts rely on the formation of adhesions for their survival, which is dependent on in growth of blood vessels from the recipient bed site. Following peripheral nerve release, a normal nerve may regain its mobility by regeneration of the gliding tissue, but this is never the case in re-explored free-nerve grafts. Free-nerve grafts are sensitive to tension and, after a graft procedure, the tension caused by mobilization is concentrated on the proximal stump and the proximal end of the graft, and the distal stump and the distal end of the graft perform minimal compensation. Therefore, when performing nerve grafts, the proximal nerve stump must have enough mobility that it will allow for range of motion of the foot and ankle without creating undue tension on the nerve graft.
**Nerve Adjuncts**

Many techniques have been employed to alter the local environment, such as fat grafts, muscle flaps, rerouting, and vascularized nerve graft. The aim is to allow the scarred nerve to heal in a new environment free of adhesions. Another adjunct used is nerve stimulation, which provides relief of symptoms by blocking the pain-signal transmission. These procedures may provide relief after all other treatment options have failed. The theory is based on sending nonpainful touch signals to the brain to interfere with pain-signal transmission and prevent the perception of pain.

**SUMMARY**

Revision peripheral nerve surgery can provide benefits to patients experiencing symptoms after a failed primary procedure. It is important to understand why the initial procedure failed and whether the symptoms are created by internal or external factors. Once the causative factors are identified by the clinical examination, radiologic, and electrodiagnostic studies, many different treatment options exist to provide relief of the patient’s symptoms and improve their quality of life. There is a more clear understanding of the clinical signs of peripheral nerve disorders, but diagnosing early peripheral nerve disorders using objective parameters continues to be elusive in a number of patients. Those with documented palpable lesions neighboring peripheral nerves or with MRI findings of a space-occupying lesion are limited in number. In patients with failed primary peripheral nerve surgery, where no clear objective lesions or pathology is present, the best course of action is commonly the more difficult decision, which is to treat them medically and to avoid additional surgery. However, given that most of the literature is supported by fair evidence (EBM Grade B–treatment options are supported by fair evidence consistent with Level III or IV studies), there are many different options available for revision peripheral nerve surgery when it is necessary.

**REFERENCES**

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