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Surgical Interventions for Lumbosacral Plexus Injuries: A Systematic Review

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Background: Nerve reconstruction techniques for lumbosacral plexus (LSP) injuries vary. There are no clear treatment guidelines available, and summative evaluations of the literature discussing these surgeries are lacking. For these reasons, this investigation aimed to systematically review and consolidate all available literature discussing surgical interventions for LSP injuries and cohesively present patient-reported and objective postoperative outcomes.
Methods: The authors conducted a systematic review using PubMed, Embase, Web of Science, ProQuest Dissertations and Theses Global (via Proquest.com), and ClinicalTrials.gov databases according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. After title and abstract screening, identified articles were read in full and selected for inclusion based on prespecified criteria.
Results: Our literature search identified 8683 potential citations, and after duplicate removal, abstract screening, and full-text review, 62 studies remained meeting inclusion and exclusion criteria. Outcomes were extracted according to the location of injury and type of surgical repair. Injuries were classified into isolated femoral nerve injuries, isolated obturator nerve injuries, isolated sciatic nerve injuries, and multilevel LSP injuries. Surgical treatment was further classified into exploration with neurolysis, direct repair, nerve grafting, and nerve transfer surgery.
Conclusions: Although results vary based on the location of the injury and the surgical technique used, nerve grafts and transfers demonstrated reasonable success in improving functional and pain outcomes. Overall, isolated femoral and obturator nerve injuries had the best outcomes reported with surgical treatment. Furthermore, incomplete sciatic nerve and multilevel LSP injuries had more reported surgical options and better outcomes than complete sciatic nerve injuries.
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INTRODUCTION

Lumbosacral plexus (LSP) injuries are uncommon and often vary in severity, with neurological deficits ranging from inconsequential to complete paralysis and hypesthesia in the lower extremities.[1–3] When severe, LSP injuries are typically the result of high-energy trauma related to pelvic fractures or the spinal column.[4,5] However, other mechanisms, such as iatrogenic or obstetric injuries, have also been reported. Recovery of function following LSP injury is variable, depending on severity at presentation and the type of treatment implemented. Historically, conservative therapy has been favored in most cases as surgical intervention can be technically demanding and associated with high morbidity.[6,7] Nevertheless, surgery

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can improve functional outcomes, reduce neuropathic pain, and increase patient satisfaction when successful.[8]

Several options exist for surgical intervention, including neurolysis, direct repair, nerve grafting, and nerve transfers. However, due to the relatively low incidence of LSP injuries, published literature discussing these techniques is scarce, consisting mainly of case reports and small retrospective series.[9,10] Nerve transfer surgery, in particular, is seldom described aside from anatomic feasibility studies and single-patient case reports. To date, a comprehensive systematic review of outcomes following surgical treatment of LSP injuries has not been published. Consequently, this investigation aims to systematically review and consolidate all available literature discussing surgical interventions for these injuries while also presenting cumulative patient-reported and objective postoperative outcomes. In so doing, we aim to provide evidence for various surgical treatments of LSP injuries at different anatomical levels.

MATERIALS AND METHODS

Literature Search and Data Extraction

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, an English-language literature search was conducted to identify full-text investigations discussing surgical interventions for LSP injuries. (**See table, Supplemental Digital Content 1**, which demonstrates search details, **http://links.lww.com/PRSGO/C98**.) Two reviewers then independently extracted demographic information, clinical data, and reported outcomes according to a predesigned protocol available through the International Prospective Register of Systematic Reviews (PROSPERO), mediated by a third reviewer.[11] Human studies were marked for inclusion per the inclusion and exclusion criteria. (**See table, Supplemental Digital Content 2**, which demonstrates inclusion and exclusion criteria, **http://links.lww.com/PRSGO/C99**.) Due to data homogeneity, the study team used a conversion chart when extracting functional outcomes so that only Medical Research Council (MRC) motor grade scores were recorded. (**See table, Supplemental Digital Content 3**, which demonstrates the MRC conversion method, **http://links.lww.com/PRSGO/C100**.)

RESULTS

Study Retrieval and Characteristics

Our primary literature search identified 8683 potential citations (Fig. 1). Sixty-two of these citations met inclusion criteria. Of these studies, 51 described living patient data (**Supplemental Digital Content 4, Table A**, study and patient demographics, **http://links.lww.com/PRSGO/C167**.),[1,8,10,12–59] three described cadaver and living patient data (**Supplemental Digital Content 4, Tables A-B**, study and patient demographics, and cadaver studies, respectively; **http://links.lww.com/PRSGO/C167**.),[6,60,61] and eight described cadaver data (**Supplemental Digital Content 4, Table B**, cadaver studies, **http://links.lww.com/PRSGO/C167**.).[62–69] Patient data were extracted and classified into four categories: (1) surgery for isolated femoral nerve injuries, (2) surgery for isolated obturator nerve injuries, (3) surgery for isolated sciatic nerve injuries, and (4) surgery for multilevel LSP injuries.

One hundred and seventy-three patients were identified. In almost all documented instances, patients had surgery for unilateral injuries. The mean age of living patients was 41.3 + 15.5 years, and while not reported in all studies, 69 men (53.5%) and 60 women (46.5%) were identified.

> **Takeaways**
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> **Question:** A comprehensive systematic review of outcomes following surgical treatment of lumbosacral plexus injuries does not exist.
>
> **Findings:** Isolated femoral and obturator nerve injuries had the best outcomes following surgery. Multilevel lumbosacral plexus injuries and isolated sciatic nerve injuries had poorer outcomes. Nerve grafts and transfers both were successful in improving functional and pain outcomes.
>
> **Meaning:** Individualizing surgical care and managing expectations for recovery after surgery for lumbosacral plexus injuries are important.

Isolated Femoral Nerve Injuries

In total, 12 articles comprising 65 patients discuss surgery for isolated femoral nerve injuries without root involvement (**see Table C, Supplemental Digital Content 4**, surgery for isolated femoral nerve injuries without root involvement, **http://links.lww.com/PRSGO/C167**.). Of these, 40 (61.5%) patients presented with iatrogenic injuries, 17 (26.2%) with injuries from back or pelvic trauma, and eight (12.3%) with laceration injuries from penetrating trauma.

Exploration with Neurolysis

Among the 12 studies describing surgeries for femoral nerve injuries, one study reports outcomes for patients undergoing exploration with neurolysis for pelvic level injuries.[50] Twenty-two patients in this study met inclusion criteria. All demonstrated reduced hip flexion and knee extension abilities preoperatively (median MRC 1, range: 0–2). While specifics regarding follow-up time could not be extracted, all patients recovered hip flexion and knee extension to median MRC 3.

Nerve Grafting

Four studies (n = 29) report outcomes for patients undergoing sural nerve grafting for isolated femoral nerve injuries.[15,48,50,56] In all cases, preoperative knee extension was absent. In one study, 23 patients were followed after surgery, with 12 recovering MRC grade 3 knee extension.[50]

Six patients from the other three studies had more detailed preoperative and follow-up information.[15,48,56] For these patients, the mean preoperative interval was 3.3 + 1.2 months. The mean graft length (n = 6) used during surgery was 7.0 + 4.4 centimeters (cm). After surgery, three patients demonstrated electrophysiologic recovery at a mean of 8.0 + 4.6 months, with one patient showing recovery at 10 months. When reported, knee extension had recovered to MRC grade 3 at 10.0 + 2.8 months (n = 4). Mean final follow-up was at 29.3 + 6.1 months, at which time, all six patients had

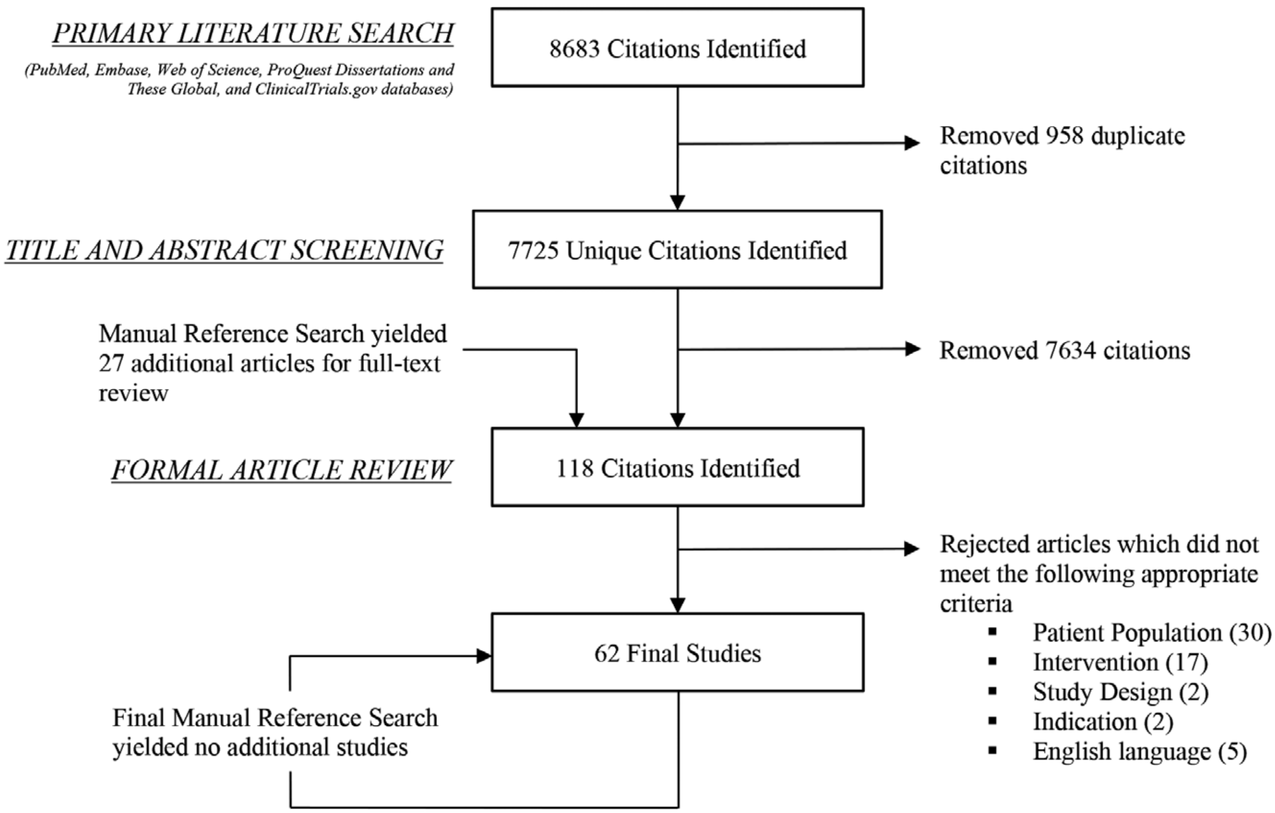

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

recovered knee extension to MRC grade 4. Overall, MRC grade 3 recovery occurred in 18 of 29 patients (62.1%).

Nerve Transfer

Nine studies (n = 14) report outcomes for patients undergoing nerve transfers for isolated femoral nerve injuries.[15–17,23,24,26,29,60,61] Two of these studies also describe cadaver data and anatomic feasibility assessments.[60,61] In all patients, preoperative knee extension was absent, with several patients also demonstrating weakened hip flexion. Preoperative electrophysiologic testing was documented in 10 patients demonstrating quadriceps denervation. The mean preoperative interval for all patients was 4.0 + 2.0 months, and the mean nerve defect length was 9.7 + 4.8 cm. In seven patients, the anterior division of the obturator nerve (ADON) was used for the transfer, and in three patients, the gracilis or adductor longus branch of the ADON was used. In three patients, the main obturator nerve was used for the transfer. In one patient, the semitendinosus branch of the sciatic nerve was elongated with a sural nerve graft and used for the transfer. Eight patients demonstrated electrophysiologic recovery at 9.0 + 2.0 months. When reported, knee extension had recovered to MRC grade 3 at 10.9 + 4.8 months (n = 12). Mean final follow-up was at 32.1 + 12.3 months, at which time, knee extension had recovered to median MRC grade 4 (range: 3–5) (n = 14).

Isolated Obturator Nerve Injuries

Twenty-one articles comprising 28 patients discuss surgery for isolated obturator nerve injuries without root involvement. (**See Table D, Supplemental Digital Content 4**, surgery for isolated obturator nerve injuries without root involvement, **http://links.lww.com/PRSGO/C167**.) All patients presented with iatrogenic injuries (100%) occurring during pelvic or abdominal surgery.

Exploration with Neurolysis

Two studies report outcomes for three patients undergoing exploration with neurolysis.[45,49] All patients presented with impaired discriminatory medial thigh sensation, neuropathic pain radiating down the medial thigh, and hip adduction weakness reported as MRC grade 2. In all cases, neurolysis of the obturator nerve was performed before it entered the obturator foramen. On average, final follow-up was at 26.0 + 19.8 months, at which time, all patients had recovered hip adduction to MRC grade 5 and had reduced pain.

Direct Repair

Fourteen studies (n = 17) report outcomes for patients undergoing direct obturator repair immediately after surgical ligation.[18,20–22,28,31,33,36,40–42,45,52,53] This was done laparoscopically in end-to-end fashion in 13 patients, with injury occurring due to electrocautery during laparoscopy in three patients. The mean length of the nerve defect before coaptation was 0.48 + 0.10 cm (n = 6). Almost all patients had functional and sensory deficits immediately after surgery, which were completely resolved by final follow-up at mean 7.2 + 5.6 months (n = 15). Overall, MRC grade 3 recovery occurred in all patients.

Nerve Grafting

Seven studies (n = 7) report outcomes for patients undergoing nerve grafting for obturator nerve injuries.[12,19,21,32,34,44,45] Six patients were repaired immediately following intraoperative nerve ligation. One patient, with functional deficits, underwent exploration and graft placement 9 months after nerve injury. In five cases, a sural nerve graft was used for repair. A genitofemoral nerve graft and nerve conduit were used in the other two cases. The mean nerve defect length was 2.1 + 1.3 cm (n = 4), and the mean nerve graft length was 3.3 + 0.6 cm (n = 3). At the final follow-up (10.1 + 6.1 months), the median MRC for hip adduction was 4 (range: 3–5). MRC grade 3 recovery occurred in all patients.

Nerve Transfer

One study reports postoperative outcomes for a patient undergoing nerve transfer for obturator nerve injury.[43] Before surgery, the patient had absent adductor compartment function and electrophysiologic evidence of denervation. Surgery occurred 8 months after injury, at which time, a branch of the femoral nerve innervating a proximal quadriceps muscle was transferred to the main trunk of the obturator nerve. Postoperatively, at 4 months, the patient had evidence of electrophysiologic recovery in the adductor brevis muscle and demonstrated recovery to MRC grade 3. At 10 months, motor function was completely recovered.

Isolated Sciatic Nerve Injuries

Three studies comprising seven patients discuss surgery for isolated sciatic nerve injuries without root involvement. (**See Table E, Supplemental Digital Content 4,** Surgery for isolated sciatic nerve injuries without root involvement, **http://links.lww.com/PRSGO/C167**.) Of these, the mechanism of injury was penetrating trauma causing a laceration for four (57.1%) patients, iatrogenic for two (28.6%), and unknown for one (14.3%). No studies discussed exploration with neurolysis or direct repair for these injuries.

Nerve Grafting

One study (n = 1) reports outcomes for nerve grafting of isolated sciatic nerve injuries.[8] This patient presented with abnormal electrophysiologic testing and absent sciatic nerve function. A sural nerve graft was used to bridge the nerve defect. Although the time to final follow-up was not reported, it was documented that the patient had improved hip abduction, hip extension, and knee extension to MRC grade 3.

Nerve Transfer

Two studies (n = 6) report outcomes for patients undergoing nerve transfer surgery for isolated sciatic nerve injuries.[38,46] The median preoperative MRC for plantarflexion was 4 (range: 4–5), for foot inversion was 4 (range: 4–5), for dorsiflexion was 0, and for foot eversion was 0. In all patients, fascicles of the tibial nerve were transferred to the main trunk of the deep peroneal nerve. As reported, five patients experienced deep peroneal motor function recovery with minimal effect on tibial nerve function at the time of final follow-up (mean 21.6 + 7.6 months). The final median MRC grade for ankle dorsiflexion was 4 (range: 0–4). The final grade for foot eversion was also 4 (range: 1–4).

Multilevel LSP Injuries

Twenty-two studies comprising 73 patients discuss surgery for multilevel LSP injuries (**see Table F, Supplemental Digital Content 4,** surgery for multilevel lumbosacral plexus injuries with or without root involvement, **http://links.lww.com/PRSGO/C167**.). In this population, the mechanism of injury was blunt trauma to the back/pelvis for 52 (71.2%) patients, iatrogenic trauma for 16 (21.9%), and penetrating trauma causing a laceration injury for 5 (6.8%). Notably, no studies discuss direct repair techniques for these multilevel injuries.

Exploration with Neurolysis

Eight studies report outcomes for 25 patients undergoing exploration with neurolysis for multilevel LSP injuries.[8,39,51,54,55,57–59] Most patients in this subgroup had sensory deficits and severe root injuries identified on preoperative imaging. In 18 patients, significant preoperative functional deficits were noted. In 10 of these patients, deficits were primarily related to hip flexion and knee extension, and in eight patients, deficits also included more distal muscle groups. Notably, preoperative functional assessments were not available for seven patients. In 13 patients, electrophysiologic testing was abnormal. Surgery was done immediately following blunt trauma in one patient. However, when reported, the mean preoperative interval was 28.8 + 31.7 months (n = 14). In some patients, this was due to late presentation. The mean final follow-up was 19.5 + 9.6 months (n = 9). At this time, eight patients reported improved neuropathic pain and functional outcomes, and nine patients recovered at least MRC 4 function in affected muscle groups. Three patients demonstrated no recovery. In general, patients with proximal dysfunction preoperatively improved more after surgery than those with distal dysfunction. Overall, MRC grade 3 recovery occurred in 12 of 15 patients with adequate follow-up (80%).

Nerve Grafting

Five studies (n = 13) report outcomes for nerve grafting of multilevel injuries.[1,8,25,47,51] Almost all patients presented with severe root injuries, sensory deficits, abnormal electrophysiologic testing, and significant functional impairments in corresponding muscle groups. Sural nerve graft was used for repair in four cases. When reported, length of the nerve grafts ranged from 7 to 45 cm. Final follow-up, provided for three patients, was at 56.3 + 36.2 months. At final follow-up, five patients had not recovered function, five (38.5%) had recovered at least MRC 3 function, and three (23.1%) had recovered at least MRC 4 function. This was especially pronounced in proximal muscle groups near the hip.

Nerve Transfer

Twelve studies (n = 35) report outcomes for patients undergoing nerve transfers for multilevel LSP injuries.[6,10,13,14,27,30,35,37,38,46,51,61] Similar to the patients who underwent grafting, most patients presented with avulsion injuries or root involvement, abnormal electrophysiologic testing, and various functional deficits depending on the involved roots. In most cases, injury involved both lumbar and sacral plexuses. For all patients, the mean preoperative interval was 5.9 + 3.9 months.

In near-complete or complete LSP injuries, the contralateral S1 nerve root (n = 6) was transferred through an intervening common peroneal nerve graft to reinnervate the inferior gluteal nerve and the branch to the hamstrings.[35,37] On the injured side, hip abduction recovered to MRC grade 3 after 1 year, and knee flexion recovered to MRC grade 3 within 1.5 years in all patients (n = 6). In addition, the authors reported a temporary decrease in hip abduction in the normal donor site in four of six patients with recovery within 6 months to 1 year. In another patient with suspected bilateral near-complete LSP injuries, intercostal nerves were transferred in the left leg, and a femoral nerve branch was transferred in the right leg. While right leg recovery was not explicitly reported, in the left leg, hip abduction and flexion recovered to MRC grade 3, and knee extension recovered to MRC grade 4.

In incomplete injuries, the trunk of the obturator nerve or its branches (n = 10), fascicles or branches of the tibial nerve (n = 9), or superficial peroneal nerve (n = 7) were transferred as donors. In addition, in two patients, multiple femoral nerve branches were transferred. At final follow-up (mean 23.7 + 8.6 months), 12 patients (34.3%) had recovered at least MRC 3 function, and five patients (14.3%) had recovered at least MRC 4 function.

Cadaver Studies

Eleven studies describe cadaveric data and the anatomic feasibility of various surgical procedures (Table 2).[6,60–69] All cadaver studies assessed nerve transfer techniques for feasibility based on the distance of the attempted transfer, fascicle or fiber counts of the proximal and distal nerve stumps, and nerve diameter of the proximal and distal nerve stumps.

DISCUSSION

The heterogeneity related to anatomical location and pattern of LSP injuries makes providing evidence-based recommendations for surgical treatment complicated.[70,71] Nevertheless, several trends were observed. Surgery for isolated femoral and obturator nerve injuries led to MRC improvement in a greater percentage of patients than other injury locations, regardless of the type of surgery attempted (neurolysis, grafting, or nerve transfers). With isolated femoral nerve injuries, most patients in the nerve grafting group reached at least MRC 3 leg extension by final follow-up (Table 1). All patients in the nerve transfer group achieved MRC 3 knee extension, with the majority also achieving MRC 4 by final follow-up (Table 2). It is important to note that while MRC 3 does not obviate the need for external support and gait, it does facilitate better-assisted gait and makes self-repositioning in bed easier. Meanwhile, MRC 4 knee extension could better lend toward unassisted ambulation.

For obturator nerve injuries, most patients underwent direct repair or nerve grafting immediately following intraoperative transection of the obturator nerve. After direct repair, all patients achieved at least MRC 4 hip adduction by final follow-up. All patients in the graft group reached MRC 3 hip adduction, with five (71.4%) also reaching MRC 4 by final follow-up.

For isolated sciatic nerve injuries, reported nerve transfers were for incomplete injuries with predominant involvement of the deep peroneal nerve.[38,46] Importantly, these patients had meaningful recovery of ankle dorsiflexion and eversion. There was also one reportedly successful nerve graft case for an incomplete injury.[8] However, only recovery of proximal function in the gluteus muscles was demonstrated in this patient. The lack of published reports on complete sciatic nerve injuries proximal to the greater sciatic foramen may suggest that surgical outcomes remain suboptimal.

Multilevel LSP injuries were the most discussed in the literature. Unfortunately, these patients had extensive deficits, making surgery challenging, direct repair impossible, and total recovery unlikely.[72] In general, surgical repair was targeted at recovery of proximal muscle groups, and multinerve repair was rarely attempted. In cases of neurolysis for these injuries, the primary reason for surgery was pelvic or sacral fracture fixation.[73,74] In many instances, this was staged, with root sheath entry and neurolysis performed during a later stage rather than during initial fracture fixation. Functionally, these patients had various levels of improvement, with Alexandre et al[8] describing the most significant return of function. In three other studies, root exploration was performed in eight patients to treat neuropathic pain during follow-up after LSP injury. Of these patients, seven demonstrated substantial pain reduction postoperatively.[54,57,59] For these reasons, neurolysis appears to be more beneficial for treating neuropathic pain rather than restoring function.

There are multiple limitations in this study to consider. Numerous studies and patients were eliminated during our literature review due to strict inclusion criteria. Although this likely limited the power and application of our data, the authors of this study found strict, defined criteria to be important in maximizing internal validity and the reproducibility of our methodology. By restricting our assessment to the LSP, this study excluded all distal injuries, which would likely have skewed our data due to their more favorable postoperative courses when compared with more proximal plexus injuries.[75] Additionally, this study did not attempt a formal meta-analysis because of substantial heterogeneity surrounding outcome reporting and small sample sizes. These factors made data extraction difficult and necessitated our use of the MRC conversion chart to minimize subjectivity.

Table 1. Outcome Summary for Functional Recovery, MRC Scale >3

Treatment	No. Studies	No. Patients	No. Patients at Final Follow-up	No. (%) Final MRC Scale >3	No. (%) Final MRC Scale <3
Isolated femoral nerve injuries	12	65	65	54 (83.1)	11 (16.9)
Exploration with neurolysis	1	22	22	22 (100)	0 (0)
Direct repair	0	0	0	—	—
Nerve graft	4	29	29	18 (62.1)	11 (37.9)
Nerve transfer	9	14	14	14 (100)	0 (0)
Isolated obturator nerve injuries	21	28	26	26 (100)	0 (0)
Exploration with neurolysis	2	3	3	3 (100)	0 (0)
Direct repair	14	17	15	15 (100)	0 (0)
Nerve graft	7	7	7	7 (100)	0 (0)
Nerve transfer	1	1	1	1 (100)	0 (0)
Isolated sciatic nerve injuries	3	7	6	4 (66.7)	2 (33.3)
Exploration with neurolysis	0	0	0	—	—
Direct repair	0	0	0	—	—
Nerve graft	1	1	1	0 (0)	1 (100)
Nerve transfer	2	6	5	4 (80)	1 (20)
Multilevel lumbosacral plexus injuries	22	73	55	37 (67.3)	18 (32.7)
Exploration with neurolysis	8	25	15	12 (80)	3 (20)
Direct repair	0	0	0	—	—
Nerve graft	5	13	13	8 (61.5)	5 (38.5)
Nerve transfer	12	35	27	17 (63.0)	10 (37.0)

Patients must have all muscle groups at or above MRC 3 to be considered in the MRC >3 category.

Table 2. Outcome Summary for Functional Recovery, MRC Scale >4

Treatment	No. Studies	No. Patients	No. Patients at Final Follow-up	No. (%) Final MRC Scale >4	No. (%) Final MRC Scale <4
Isolated femoral nerve injuries	12	65	65	18 (27.7)	47 (72.3)
Exploration with neurolysis	1	22	22	0 (0)	22 (100)
Direct repair	0	0	0	—	—
Nerve graft	4	29	29	6 (20.7)	23 (79.3)
Nerve transfer	9	14	14	12 (85.7)	2 (14.3)
Isolated obturator nerve injuries	21	28	26	24 (92.3)	2 (7.7)
Exploration with neurolysis	2	3	3	3 (100)	0 (0)
Direct repair	14	17	15	15 (100)	0 (0)
Nerve graft	7	7	7	5 (71.4)	2 (28.6)
Nerve transfer	1	1	1	1 (100)	0 (0)
Isolated sciatic nerve injuries	3	7	6	3 (50)	3 (50)
Exploration with neurolysis	0	0	0	—	—
Direct repair	0	0	0	—	—
Nerve graft	1	1	1	0 (0)	1 (100)
Nerve transfer	2	6	5	3 (60)	2 (40)
Multilevel lumbosacral plexus injuries	22	73	55	17 (30.9)	38 (69.1)
Exploration with neurolysis	8	25	15	9 (60)	6 (40)
Direct repair	0	0	0	—	—
Nerve graft	5	13	13	3 (23.1)	10 (76.9)
Nerve transfer	12	35	27	5 (18.5)	22 (81.5)

Patients must have all muscle groups at or above MRC 4 to be considered in the MRC >4 category.

Furthermore, most studies in this data set include case series or reports with no comparison group, which further precluded a formal analysis. Instead, descriptive statistics were calculated to demonstrate an overall idea of data summary.

This is the first systematic review to our knowledge that investigates LSP injuries and their surgical treatments. We are hopeful that these summative data, describing each surgical technique, will be helpful to nerve surgeons who encounter patients presenting for treatment of these uncommon and devastating injuries. In general, nerve grafts and transfers demonstrated reasonable success in improving functional and pain outcomes with superior outcomes in isolated femoral and obturator nerve injuries. For LSP injuries, individualizing surgical care and carefully managing expectations for recovery are essential when discussing treatments with patients.

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