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Exhibit Selection

Peripheral Nerve Injuries in Sports-Related Surgery: Presentation, Evaluation, and Management

AAOS Exhibit Selection

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Abstract: Peripheral nerve injuries during sports-related operative interventions are rare complications, but the associated morbidity can be substantial. Early diagnosis, efficient and effective evaluation, and appropriate management are crucial to maximizing the prognosis, and a clear and structured algorithm is therefore required. We describe the surgical conditions and interventions that are commonly associated with intraoperative peripheral nerve injuries. In addition, we review the common postoperative presentations of patients with these injuries as well as the anatomic structures that are directly injured or associated with these injuries during the operation. Some examples of peripheral nerve injuries incurred during sports-related surgery include ulnar nerve injury during ulnar collateral ligament reconstruction of the elbow and elbow arthroscopy, median nerve injury during ulnar collateral ligament reconstruction of the elbow, axillary nerve injury during Bankart repair and the Bristow transfer, and peroneal nerve injury during posterolateral corner reconstruction of the knee and arthroscopic lateral meniscal repair. We also detail the clinical and radiographic evaluation of these patients, including the utility and timing of radiographs, magnetic resonance imaging (MRI), ultrasonography, electromyography (EMG), and nonoperative or operative management. The diagnosis, evaluation, and management of peripheral nerve injuries incurred during sports-related surgical interventions are critical to minimizing patient morbidity and maximizing postoperative function. Although these injuries occur during a variety of procedures, common themes exist regarding evaluation techniques and treatment algorithms. Nonoperative treatment includes physical therapy and medical management. Operative treatments include neurolysis, transposition, neurorrhaphy, nerve transfer, and tendon transfer. This article provides orthopaedic surgeons with a simplified, literature-based algorithm for evaluation and management of peripheral nerve injuries associated with sports-related operative procedures.

Peripheral nerve injuries during sports-related surgical interventions are rarely reported. Data obtained from a national survey performed by members of the Arthroscopy Association of North America documented sixty-three neurological complications, representing 6.8% of all complications recalled by the participating surgeons, following 118,590 arthroscopic surgical cases[1]. Although these represent a minority of the sustained complications, the associated morbidity of the nerve injuries can be substantial and permanent. These injuries occur with both open and arthroscopic intervention, and the severity and management vary considerably among specific types of nerve injuries.

This article focuses on the sports-related surgical procedures most commonly reported to be associated with iatrogenic

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TABLE I Surgical Anatomy: Important Landmarks and Relationships

Surgical anatomy: upper extremity	
Shoulder arthroscopy (axillary, musculocutaneous, subscapular nerves)	
Posterior portal	Located 3-4 cm superior to axillary nerve in quadrangular space[31]
Anterior portal	Musculocutaneous, axillary, and subscapular nerves lie inferior and lateral to coracoid process at level of anterior portal. Brachial plexus lies medial to coracoid process at level of anterior portal[31]
Lateral portal	Axillary nerve enters deep surface of deltoid approximately 5 cm distal to lateral aspect of acromion. Smaller branches may enter deltoid 1 cm distal to lateral aspect of acromion
Elbow arthroscopy (musculocutaneous, radial, medial antebrachial cutaneous, median, ulnar nerves)	
Midlateral portal	Lies 7 mm from posterior antebrachial cutaneous nerve[32]
Posterolateral portal	Lies 20 mm from medial antebrachial cutaneous nerve (MABCN) and 25 mm from ulnar nerve[33]
Anteromedial portal	Lies 1 mm from MABCN, 4 mm from median nerve. Flexion of elbow and distention of joint with saline solution increases distance of portal from median nerve to 14 mm[33]
Anterolateral portal	Lies 3 mm posterior to radial nerve, 7-11 mm with joint distention. Lies 2 mm anterior to posterior antebrachial cutaneous nerve
Direct biceps repair (median, posterior interosseous nerves)	
Distal biceps insertion on radial tuberosity lies 12 mm from medial nerve, 18 mm from posterior interosseous nerve (PIN)[34]	
Lateral antebrachial cutaneous nerve injury is the most common (up to 40% in some series); median nerve injury is the most serious	
Steinmann pin fixation of the biceps should be performed directly posterior rather than at oblique 45° angle. At 0°, distance to PIN is 14 mm. At 45°, distance decreases to 8 mm	
Surgical anatomy: lower extremity	
Periarticular knee surgery (peroneal, saphenous nerves)	
Peroneal nerve passes just beneath biceps tendon, crossing obliquely across fibula[35]. Anatomic variability can lead to iatrogenic injury; 20% of patients will have separate deep and superficial peroneal nerve at level of lateral joint line; 19% of patients will have continuation of common peroneal nerve below level of fibular neck[36]	
Saphenous nerve lies beneath sartorius muscle and passes distally between sartorius and gracilis tendons[35].	
Sends off an anterior infrapatellar branch to the knee.	
Distal sartorial branch crosses inferolaterally at level of pes anserinus (lies in surgical field during anterior cruciate ligament surgery)	
Ankle arthroscopy (superficial peroneal nerve)	
Superficial peroneal nerve lies lateral to peroneus tertius tendon in 11.8% and at its lateral edge in 27.5%[30]	

nerve injury. The anatomy pertinent to these described surgical approaches will also be discussed. Additionally, the diagnostic modalities employed in evaluation of these injuries will be reviewed, along with nerve-specific treatment options and outcomes related to iatrogenic nerve injury. Finally, an algorithm for identification and management will be detailed to serve as a guide for evaluating and managing peripheral nerve injuries in sports-related surgery.

Relevant Anatomy

A thorough understanding of the relevant anatomy is crucial to achieving successful surgical outcomes and minimizing complications. Specific anatomic relationships must be appreciated prior to each surgical approach in either the upper or lower extremities.

Upper Extremity

Multiple studies have documented nerve injury in the upper extremity, including injury to the axillary, musculocutaneous, radial, median, and ulnar nerves[2-5]. These injuries have been associated with procedures including the Bristow transfer[2,5], Bankart repair[5], ulnar collateral ligament (UCL) reconstruction[6], and elbow arthroscopy[7], among others. Care must be exercised during dissection and arthroscopic portal placement about the shoulder and elbow because of the superficial nature and close proximity of the neural anatomy (Table I).

Lower Extremity

Injuries to the sciatic, lateral femoral cutaneous, and common and superficial peroneal and saphenous nerves have been documented during surgery about the hip, knee, and ankle, respectively[8-18]. Knowledge of the relative neural anatomy and anatomic landmarks for portal placement and dissection intervals will aid in minimizing these injuries and their potential consequences (Table I).

Classification Systems and Nerve Injury Prognosis

Classification Systems

There are two main classification systems for neurologic injury, the Seddon and Sunderland systems. The Seddon grading is based primarily on the results of nerve conduction studies, and it divides peripheral nerve injury into three categories: neurapraxia, axonotmesis, and neurotmesis (Table II). Neurapraxia is defined as a nerve compression injury in which

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TABLE II Sunderland and Seddon Classification Systems*

Sunderland	Seddon	Tinel Sign	Distal Progression	Recovery Pattern	Rate of Recovery	Surgery
Type I	Neurapraxia	None	Rapid	Full	Rapid (days to 3 months)	None
Type II	Axonotmesis	+	+	Full	Slow (3 cm/mo)	None
Type III		+	+	Variable	Slow (3 cm/mo)	Variable
Type IV		+	No progression	None	None	Yes
Type V	Neurotmesis	+	No progression	None	None	Yes

*These classification systems have been used to define the severity of neurologic injury and aid in assessing potential nerve recovery.

the axon is intact but local myelin injury and a conduction block are present. Axonotmesis is defined as a nerve crush injury in which there is axonal interruption with intact Schwann cells and conduction failure. Neurotmesis carries the worst prognosis for recovery and is characterized by a nerve transection injury that results in axonal interruption, connective tissue disruption, and complete conduction failure.

The Sunderland grading system divides the injury into five grades on the basis of the anatomic extent of the nerve injury. Type-I injury represents an isolated nerve conduction block. In Type-II injury, a complete loss of axonal continuity exists in addition to the conduction block. Type-III injury involves loss of continuity of both the axon and the endoneurium. The severity of injury increases in Type IV to include loss of continuity of the perineurium as well as the axon and endoneurium. The most severe type is Type V, in which complete transection of the entire neural trunk including the epineurium exists.

The Seddon grading system corresponds roughly with the Sunderland system in that neurapraxia is equivalent to Sunderland Type I, axonotmesis to Types II to IV, and neurotmesis to Type V. These systems have been correlated with potential neural recovery (Table II). The Seddon classification is commonly used clinically because of its close association with prognosis and its descriptive ease. Neurapraxia is defined by a local conduction block without the presence of wallerian degeneration, and it is associated with a variable sequence and rate of recovery; the prognosis for full recovery is good to excellent. Axonotmesis is defined by wallerian degeneration with conservation of the endoneurial tube; the prognosis is for recovery over a period ranging from four to nine months. Neurotmesis is the most severe class of nerve injury. Recovery occurs in a sequential fashion and is only possible with surgical repair. The rate of recovery along the repaired nerve ranges from 1 to 5 mm per day and varies depending on patient age.

Patient Evaluation

A thorough clinical history is important in determining the appropriate diagnosis and treatment plan. Individual characteristics play a crucial role, as the same treatment choice is rarely optimal in all patients. The examining physician should consider patient age, occupation, avocations, and hand dominance when determining the treatment risks and benefits. Exacerbating activities, duration of symptoms, qualitative weakness, prior injury or surgery, neurologic history, and functional deficits may help to narrow the differential diagnosis and optimize treatment planning.

Physical examination for nerve injury is a useful objective measure of injury severity. This examination should determine the nerve injury location and identify whether the lesion is partial or complete. Inspection of the affected limb can reveal associated muscle atrophy or abnormal extremity positioning. Patients assessed during the first forty-eight hours after cutaneous nerve injury will exhibit skin that is dry (anhidrosis) and warm (vasomotor paralysis) in the affected distribution. Lost or diminished sensation, paralysis or diminished strength, and pain or altered sensations over the affected nerve distribution are early signs of nerve injury. These signs must be carefully assessed on the initial examination. Two-point discrimination and pinprick and vibratory sensation should be tested when possible. Less than 6 mm on a static two-point discrimination test is considered within a "normal" range. The Tinel test is often positive in the setting of a contused or severed nerve, and it can also be used to monitor nerve regeneration on subsequent examinations.

If a motor or mixed nerve is involved, strength testing of all muscles distal to the affected area should be performed, most commonly with use of the Medical Research Council grading system (Table III). A complete neurological examination of the involved area must be performed to fully define the injury (Table IV).

Diagnostic Evaluation

Imaging studies and electrodiagnostic testing play an important role in the evaluation of a patient with a suspected iatrogenic

TABLE III Medical Research Council Scale for Motor Nerve or Muscle Function During Physical Examination

Grade	Function
0	No contraction
1	Flicker or trace of contraction
2	Active movement with gravity eliminated
3	Active movement against gravity
4	Active movement against gravity and resistance
5	Normal power

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TABLE IV Pertinent Motor and Sensory Innervation: Function and Signs Suggestive of Injury

Nerve-specific examination: upper extremity	
Axillary nerve	
Muscles innervated	Middle and anterior deltoid (anterior division of axillary nerve), posterior deltoid, and teres minor (posterior division of axillary nerve)
Function	Shoulder abduction to 90°, transverse extension, and external rotation
Sensory contributions	Sensation over lateral aspect of proximal aspect of humerus
Injury findings	Weakness in shoulder forward flexion, numbness in lateral aspect of shoulder
Radial nerve	
Muscles innervated	Triceps brachii, brachioradialis, posterior compartment of forearm
Function	Elbow extension; forearm supination; wrist, finger, and thumb extension
Sensory contributions	Posterior brachial cutaneous nerve: sensation over posterior aspect of arm.
	Posterior antebrachial cutaneous nerve: sensation over middle 1/3 of posterior aspect of arm.
	Superficial branch of radial nerve: sensation to dorsoradial aspect of wrist and hand.
	Lateral branch: sensation to dorsoradial aspect of thumb.
	Medial branch: sensation to dorsum of index finger, middle finger, and radial aspect of ring finger
Injury findings	Elbow, wrist, and digit extensor weakness; dorsal arm, forearm, and hand numbness (1st thenar web space)
Musculocutaneous nerve	
Muscles innervated	Coracobrachialis, biceps brachii, brachialis
Function	Coracobrachialis: flexion and adduction of shoulder joint with arm flexed and laterally rotated at the shoulder joint, elbow flexed, and forearm supinated
	Biceps brachii: forearm supination and resisted elbow flexion with forearm supinated
	Brachialis: elbow flexion with neutral forearm rotation
Sensory contributions	Lateral antebrachial cutaneous nerve: provides sensation to volar lateral aspect of forearm
Injury findings	Weakness in elbow flexion and forearm supination; radial forearm numbness
Ulnar nerve	
Muscles innervated	Pronator teres, flexor carpi radialis, flexor digitorum superficialis, palmaris longus, flexor pollicis longus*, flexor digitorum profundus to index and middle fingers*, pronator quadratus*, abductor pollicis brevis, flexor pollicis brevis (superficial head), opponens pollicis, lumbricals to index and middle fingers (* = supplied by anterior interosseous branch)
Function	Wrist flexion and ulnar deviation, finger flexion, metacarpophalangeal joint flexion, proximal interphalangeal joint extension, finger abduction and adduction, thumb adduction and flexion
Sensory contributions	Dorsal branch of the ulnar nerve: sensation over dorsal ulnar aspect of hand
	Common and proper digital nerves: sensation to small finger and ulnar aspect of ring finger
Injury findings	Interosseous and hypothenar wasting (Wartenberg sign, Froment sign), claw hand (with high ulnar nerve injury), decreased sensation to small finger and ulnar aspect of ring finger
Median nerve	
Muscles innervated	Triceps brachii, brachioradialis, posterior compartment of forearm
Function	Elbow extension; forearm supination; wrist, finger, and thumb extension
Sensory contributions	Palmar cutaneous branch: sensation to thenar area of hand.
	Common and proper digital nerves: sensation to volar aspect of thumb, index finger, middle finger, and radial aspect of ring finger
Injury findings	Loss of thumb interphalangeal joint flexion, index and long finger distal interphalangeal joint flexion, forearm pronation, and thumb opposition. Thenar atrophy; decreased sensation to thumb, index finger, long finger, and radial half of ring finger
Nerve-specific examination: lower extremity	
Sciatic nerve	
Muscles innervated	Semimembranosus, semitendinosus, biceps femoris
Function	Knee flexion
Sensory contributions	None in the thigh; provides sensation to the leg and foot via its distal branches
Injury findings	Weakness in knee flexion

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TABLE IV (*continued*)

Common peroneal nerve	
Muscles innervated	Peroneus longus, peroneus brevis, peroneous tertius, tibialis anterior, extensor hallucis longus, extensor digitorum longus
Function	Ankle dorsiflexion and eversion, toe extension
Sensory contributions	Lateral sural cutaneous nerve: sensation to posterior and lateral aspects of leg
	Medial dorsal cutaneous nerve: sensation to dorsum of foot, medial side of hallux, and 2nd-3rd toe web space
	Intermediate dorsal cutaneous nerve: sensation to dorsolateral aspect of foot and to 3rd-4th and 4th-5th toe web spaces
	Medial terminal branch of deep peroneal nerve: sensation to 1st web space
Injury findings	Foot drop and eversion weakness, dorsal foot numbness
Lateral femoral cutaneous nerve	
Muscles innervated	None
Sensory contributions	Sensation to anterolateral aspect of proximal aspect of thigh
Injury findings	Lateral thigh numbness
Saphenous nerve	
Muscles innervated	None
Sensory contributions	Sensation to medial aspect of thigh, leg, and foot
Injury findings	Medial thigh, leg, and foot numbness

nerve injury. Each case must be considered separately to make the most efficient and appropriate use of the tests that are at the disposal of the treating physician.

In most cases, radiographs will be of limited utility. In cases of suspected compression due to implant impingement or other causes, radiographs may be an appropriate first step.

Magnetic resonance imaging (MRI) of suspected nerve injuries could be used in identifying associated pathology and the zone of injury. T2-weighted and short tau inversion recovery (STIR) sequences are excellent for identification of peripheral nerve trauma. The addition of gadolinium can enhance detection of suspected lesions. The magnet strength and quality, sequence, and radiologist add a great deal of subjectivity to the interpretation of the images, and MRI is therefore not considered a gold-standard diagnostic modality.

Modern ultrasonographic techniques are also effective for identifying peripheral nerve lesions. High-frequency transducers utilized in clinical practice can achieve a spatial resolution of 400 μm. In particular, axonal swelling, neuroma formation, nerve compression, and nerve continuity are easily assessed with this modality. Ultrasonography is particularly operator-dependent, but it can be an excellent adjunct if utilized correctly.

Electrodiagnostic testing is typically the most important objective clinical test in the work-up of peripheral nerve lesions. Electromyography (EMG) and nerve conduction velocity studies (NCS) can help to elucidate the etiology of a nerve-related injury (e.g., compression or traumatic neuropathy), determine the severity of the injury, and aid in determining the prognosis for recovery.

During a nerve conduction study, a peripheral nerve is stimulated and the signal is recorded either in the more distal portion of the nerve or in the innervated muscle. Signal conduction speed, time from stimulus to maximum response, and amplitude of the action potential are measured and compared with normal values. This comparison often reveals important information regarding axonal loss and demyelination (Table V).

EMG is used to evaluate muscle function. Depending on the type and chronicity of nerve injury, different characteristic EMG patterns may be seen (Table V). The response to insertion of the needle; the presence of abnormal spontaneous potentials such as positive sharp waves, fibrillations and fasciculations; and the shape and duration of the motor unit potential all play a role in characterizing and diagnosing the peripheral nerve lesion.

Surgery and Management According to Anatomic Location

Shoulder

Axillary nerve injury has been documented during various procedures including the Bristow transfer[2,5] and Bankart repair[5]. The axillary nerve courses near the anteroinferior border of the glenohumeral capsule and the inferior border of the subscapularis muscle. Care must be used during dissection and portal placement in this region. Preventive measures that should be used during dissection include careful nerve identification and retractor use. If a permanent axillary nerve injury occurs, successful management may include free sural nerve grafting at three to six months postoperatively. This management has been shown by other authors to result in successful recovery of strength to grade 4 of 5 and return to sports without recurrent instability[5]. We have also successfully managed this complication by transferring the nerve innervating the medial head of the triceps to the anterior axillary nerve.

The Bristow transfer has also been associated with injury to the musculocutaneous nerve resulting from anatomic variations[2]. The proximal division of the musculocutaneous nerve

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TABLE V Use of Electromyography and Nerve Conduction Studies*

	Electromyography		Nerve Conduction Studies	
	Fibrillations	Voluntary Muscle Unit Action Potential	Sensory and Motor Latency	Compound Motor Action Potential/ Sensory Nerve Action Potential
Intact	None	Present	Normal	Normal
Nerve block/neurapraxia	None	None	None across the block, normal above and below	Normal above and below the block
Complete lesion/axonotmesis, neurotmesis	Present	None	Absent	Absent
Incomplete	Present	Decreased in distribution of injury	Normal or slightly prolonged	Reduced

*Results should be used to establish a baseline for the severity of the nerve injury and may be used to evaluate recovery. Results can also be used in conjunction with the physical examination to guide injury classification.

may course into the proximal aspect of the conjoined tendon, and transfer of this tendon may therefore cause tenting and increased tension on this branch following successful transfer. For this reason, identification of the musculocutaneous nerve prior to tendon transfer is suggested, and if the aforementioned anomalous anatomy is identified, transfer of the tendon should be aborted or a complete neurolysis should be completed prior to tendon transfer. If injury to the musculocutaneous nerve is identified following the tendon transfer, successful management should include complete neurolysis[2].

Elbow

Elbow arthroscopy and reconstruction of the ulnar collateral ligament of the elbow have been associated with neurologic injury to the radial, median, and ulnar nerves and their various branches in up to 14% and 31% of cases, respectively[7,19,20]. Successful prevention of neurologic injury during these procedures should consist of attention to local anatomic landmarks and identification and marking of the ulnar nerve where it is palpable proximally, distally, and within the cubital tunnel. Additionally, fluid distention of the elbow capsule can aid in displacing neurovascular structures away from portal placement sites and thereby reduce injury risk. Finally, portal creation should involve use of a scalpel through the skin only, followed by blunt trocar penetration through the deep layers and capsule.

The radial nerve is at particular risk during placement of an anterolateral portal, which is most commonly located 5 to 10 mm posterolateral to the radial nerve[7]. This anatomic relationship results in increased risk from unusually proximal portal placement. Notably, arthroscopic contracture release has been associated with a particularly high risk of radial nerve injury[21]. For these reasons, careful placement of the anterolateral portal relative to local anatomic landmarks and cautious debridement in the posterior compartment during contracture release will minimize the risk of neurologic injury. Moreover, flexion of the elbow to 90° will assist in displacing vital structures in the antecubital fossa away from the portal placement site. However, if radial nerve injury is identified postoperatively and there is no evidence of return of function, successful management has been achieved with nerve exploration and either sural nerve grafting, in the presence of an anatomic nerve defect, or adaptation with epineurial sutures, in the absence of a defect[4].

Injury to the ulnar nerve has been documented following elbow arthroscopy and ulnar collateral ligament reconstruction[20]. Ulnar neuropathy has the worst prognosis for return of motor function, and intrinsic hand weakness may never resolve. Particular importance must be placed on the patient history, specifically regarding the possibility of a prior ulnar nerve transposition. The ulnar nerve should always be palpated in the cubital tunnel, proximally, and distally. This palpation is crucial if a prior transposition has occurred, as the nerve can often be palpably mapped in its new position anterior to the cubital tunnel. If the patient has had a prior ulnar nerve transposition, the surgeon should consider an open rather than arthroscopic approach to address the elbow pathology. A muscle-splitting approach and use of the docking technique for ulnar collateral ligament reconstruction has been associated with a reduced risk of ulnar nerve injury. Concomitant ulnar nerve transposition should only be considered if the patient has preoperative symptoms of ulnar nerve compression or injury. Effective management of a postoperative ulnar nerve injury following sports-related elbow surgery may include neurolysis or transposition, or sural nerve intercalary grafting if a full-thickness defect is present[3].

Elbow arthroscopy may also lead to iatrogenic injury of the median nerve, as the anteromedial portal is created 7 to 20 mm from the median nerve. Particular care must be taken if arthroscopy is conducted in a posttraumatic situation, especially if a history of ipsilateral elbow fracture exists. This situation has been associated with an increased risk of median nerve injury, as altered anatomy is frequently present and neurovascular structures may be abnormally displaced. In addition, arthroscopic resection of the coronoid process

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should be performed carefully because of the close anatomic proximity of the median nerve in this location. Consideration should be given to open debridement in posttraumatic situations or if the elbow is severely fibrotic. In the event that a postoperative median nerve palsy is identified, successful management has included exploration or sural nerve grafting, or repair with epineurial sutures if sufficient median nerve remnant is present[4].

Hip

Surgery about the hip joint, including acute or chronic proximal hamstring repair and hip arthroscopy, has been associated with injury to the sciatic, pudendal, and lateral femoral cutaneous nerves[8-11,22]. During proximal hamstring repair, the sciatic nerve should be identified proximally at the level of the ischial tuberosity where it lies lateral to the biceps femoris muscle. A variable distal anatomic course may exist between the biceps femoris and medial hamstring muscles. In addition, the posterior cutaneous nerve of the thigh should be identified and protected at the proximal-medial aspect of the gluteus-adductor margin. Particular attention should be paid during tendon mobilization from surrounding scar tissue and chronic hematoma, as an increased risk of sciatic nerve injury exists during this dissection. Prior to attempted repair, the sciatic nerve should also be identified and protected to reduce the risk of injury during dissection or nerve compression following the repair. Dissection assistance by a microvascular hand surgeon may be particularly helpful during repair of a chronic injury of the proximal hamstring that involves substantial scarring and may require neurolysis. Notably, scar tissue and neural tissue may have a similar appearance in the setting of a chronic injury. Successful management of postoperative sciatic neuropathy may include observation and orthotic stabilization for two to three months with appropriate diagnostic evaluation, followed by exploration and neurolysis or grafting if no improvement is demonstrated by three months postoperatively[23].

Advances in surgical techniques and instrumentation have led to the increasing utilization of hip arthroscopy for treatment of periarticular hip pathology. Unfortunately, injury to the lateral femoral cutaneous nerve has been reported following hip arthroscopy[10,11] because this nerve lies approximately 3 mm from the anterior portal. Superficial palpable landmarks should be used during portal placement to minimize this risk. The anterior portal should be created at the intersection of a line established distal to the anterior superior iliac spine in line with the femur and a transverse line at the level of the superior pole of the greater trochanter. As is the case during elbow surgery, only the skin should be sharply incised, followed by blunt trocar dissection into the joint to minimize the risk of nerve laceration. Additionally, the anterior portal should be established under direct intra-articular visualization. Management of postoperative injury to the lateral femoral cutaneous nerve most commonly involves observation only; however, neurolysis and neuroma excision may be required in rare, painful cases and have had successful outcomes[24].

Knee

Injury to the peroneal and saphenous nerves has been documented following open and arthroscopic periarticular surgery of the knee[12-14]. Arthroscopic lateral meniscectomy and meniscal repair have been specifically identified as procedures associated with risk of injury to the common and deep peroneal nerves. Medial meniscectomy and meniscal repair may place the saphenous nerve at risk for injury or entrapment[13,14,25,26]. The common peroneal nerve lies posterior and deep to the biceps femoris, thereby resulting in particular risk during suture passage in the posterolateral portion of the knee. Peicha et al.[26] suggested that a "figure-four," or flexed-knee, position may minimize the risk of peroneal nerve injury during lateral compartment procedures compared with the risk in full knee extension. Other authors have utilized a posterior incision and open retraction for suture needle deflection to optimize visualization and minimize iatrogenic injury to the posterolateral neurovascular structures[12]. These methods were employed to minimize the risk of nerve puncture, excessive nerve tension, and inadvertent incorporation of the neural bundle during suture fixation. Use of a posterolateral trocar has also been suggested; however, placement of this trocar may inherently place the posterolateral structures at risk for injury, specifically in the case of an anomalously proximal sciatic nerve division and subsequent altered position of the common peroneal nerve. For this reason, we do not suggest use of a posterolateral trocar, but rather an open accessory posterior incision, for posterolateral inside-out meniscal repair. Nevertheless, despite careful dissection and protective measures, postoperative peroneal nerve palsy may occur. In these circumstances, management of peroneal palsy with neurolysis has previously proven effective[14]. Common and deep peroneal nerve palsy may also require a free sural nerve intercalary graft if a substantial defect is identified intraoperatively[13].

Medial meniscectomy and repair may place the saphenous nerve at risk for injury or entrapment. The infrapatellar branch of this nerve lies deep to the sartorius muscle and inferior to the medial joint line. Injury may occur during spinal needle passage or posteromedial portal placement. Additionally, entrapment of the saphenous nerve may occur during outside-in or inside-out medial meniscal repair. In fact, iatrogenic saphenous nerve injury is the most common nerve injury following knee arthroscopy[27]. Careful portal creation, using an incision isolated to the skin followed by blunt dissection parallel to the nerve orientation with subsequent trocar placement, may minimize this injury risk. Additionally, 90° of knee flexion will displace the neural bundle posteriorly away from the portal placement site. Finally, careful spinal needle placement and reduction of needle passage attempts will also minimize the risk of nerve injury. If a postoperative saphenous nerve injury is identified, effective management commonly includes careful observation, but neurolysis or neuroma excision has been required in some cases[27].

Ankle

Recent advances in surgical techniques and instrumentation have produced an increase in treatment using ankle arthroscopy.

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TABLE VI Guidance of Surgical Management*

Surgery	Nerve Ends Approximate	Vascularized Bed	Graft Possible	Proximal Portion Intact	Distal Portion Intact
End-to-end closure	Yes	Yes	Yes	Yes	Yes
Nerve graft	No	Yes	Yes	Yes	Yes
Vascularized graft	No	No	Yes	Yes	Yes
Conduit	No	No	No	Yes	Yes
Nerve transfer	No	No	No	No	Yes

*Nerve injury severity, specifically the size of the injury defect and the presence or absence of a proximal and a distal nerve stump, is fundamental in guiding surgical management.

Although surgical dissection is minimized with an arthroscopic approach, iatrogenic palsy of the superficial peroneal nerve is the most commonly identified postoperative palsy and has been associated with creation of the anterolateral portal[16]. The intermediate dorsal cutaneous branch of the superficial peroneal nerve has been identified in close proximity to this portal location[28]. Saphenous, deep peroneal, sural, and posterior tibial nerve injury may also occur when anteromedial, anterocentral, posterolateral, and posteromedial portals are established, respectively[15-18]. Vertical portals parallel to the anatomical orientation of the nerve should be used, and the anterolateral portal should be created 2 mm lateral to the peroneus tertius to minimize the risk of injury to the superficial peroneal nerve. These neural structures lie in close proximity to the ankle capsule because of the superficial ankle anatomy. Therefore, care must be taken to avoid capsular penetration during intra-articular use of a motorized shaver for synovectomy or other related procedures. Orientation of the shaver blade at a 90° angle to the capsule can minimize an inadvertent arthrotomy. These measures should be combined to minimize the risk of nerve injury. Nevertheless, if postoperative nerve palsy is identified, effective management will commonly include observation for approximately two to three months. Management of deep peroneal nerve palsy should include the use of an ankle-foot orthosis to minimize development

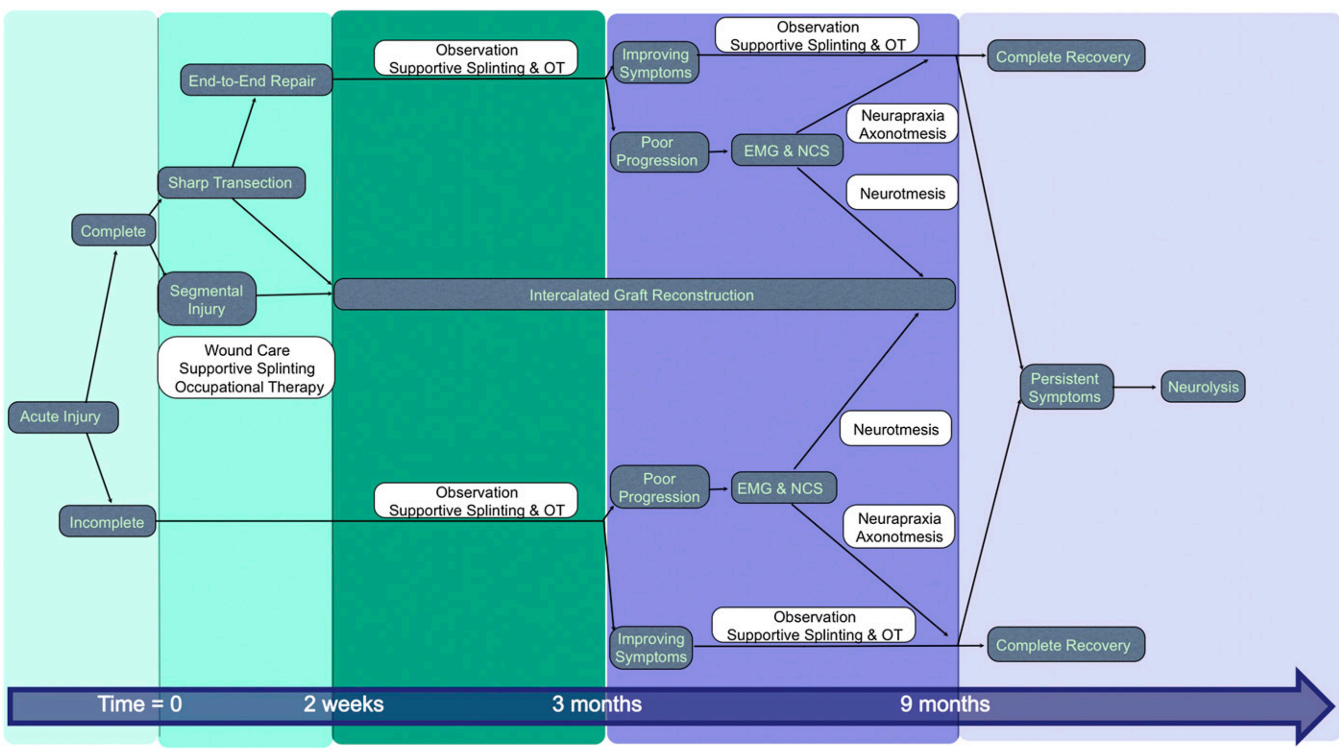

Fig. 1

The evaluation and treatment algorithm following nerve injury has three critical time points: two weeks, three months, and nine months. These time points correspond with periods of specific evaluation, intervention, and management. OT = occupational therapy, EMG = electromyography, and NCS = nerve conduction velocity studies.

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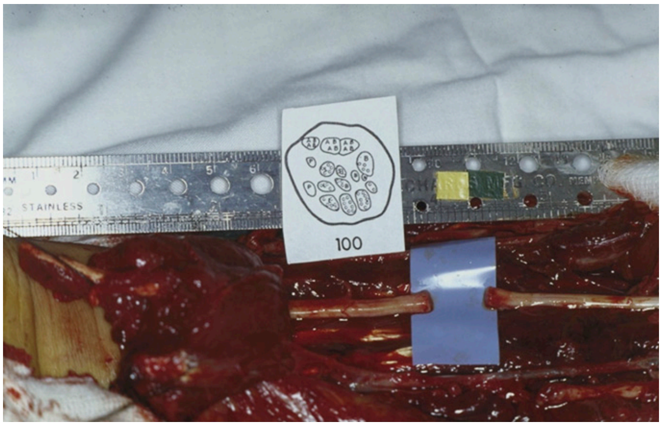

Fig. 2-A

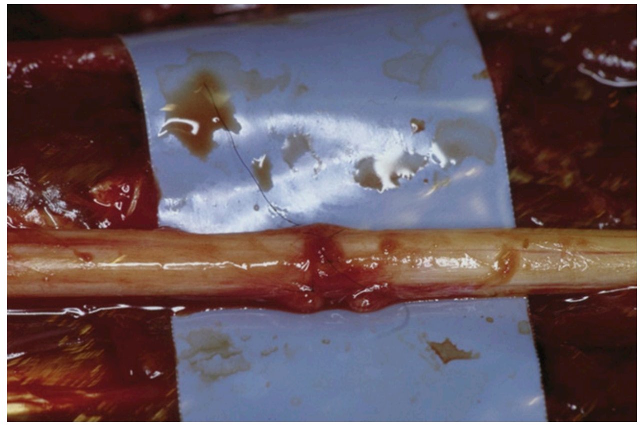

Fig. 2-B

Fig. 2-A Sharp nerve transection with minimal retraction and no defect. The diagram inset depicts the fascicular architecture in this case. **Fig. 2-B** Primary end-to-end anastomosis of the lacerated nerve.

of a plantar flexion contracture during this nerve recovery period. Surgical neurolysis and tendon transfers have also been utilized in the setting of poor nerve recovery[29,30].

Evaluation and Treatment Algorithm

The treatment algorithm for peripheral nerve injury is primarily divided into treatment for either complete or incomplete nerve injury, and it has three critical time points: two weeks, three months, and nine months (Fig. 1). If a complete sharp nerve transection is suspected on the basis of the injury mechanism, immediate surgical exploration should be performed to identify the type of transection (Table VI). A sharp transection with a minimal defect may be treated with a primary end-to-end repair, which should be performed within two weeks of the initial injury (Figs. 2-A and 2-B). On the other hand, a segmental injury or large defect will require reconstruction with a free intercalary graft (Figs. 3-A and 3-B). This reconstruction should also be performed as early as possible to optimize patient outcome, but it may be performed up to nine to twelve months after injury if necessary.

Unlike suspected acute sharp nerve laceration, acute incomplete nerve palsy should be managed with initial observation for a minimum of three months. In all cases, we suggest obtaining EMG and NCS data three weeks following the initial injury to establish a baseline for future comparison, aid in identifying the severity of an incomplete injury, and monitor nerve recovery after a repair. Follow-up EMG and NCS data should also be obtained at the three-month time point if no improvement is reported by the patient or evident on physical examination. The results of those studies, when compared with the index results, can suggest or discount evidence of subclinical nerve recovery. The results of the studies can be used in concert with the history and physical examination to classify the severity of the nerve injury and to provide guidance regarding prognosis and treatment. Continued observation should be employed if clinical evidence of improvement exists

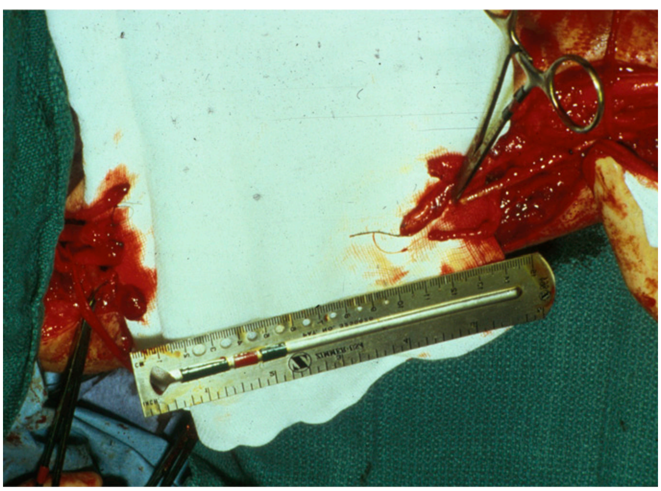

Fig. 3-A

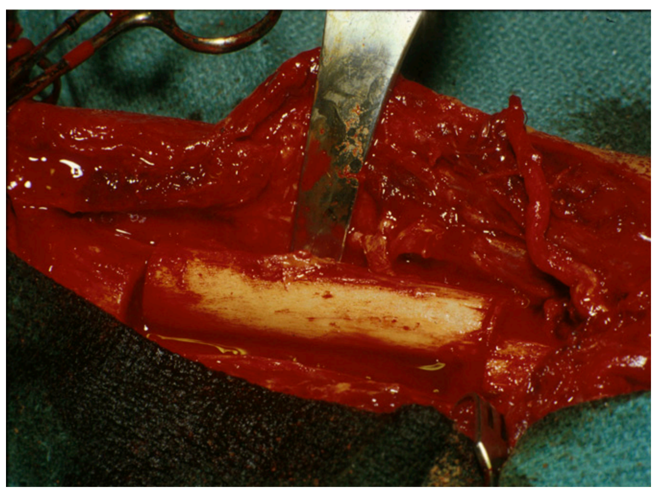

Fig. 3-B

Fig. 3-A Nerve injury with large defects that will require free intercalary nerve grafting. **Fig. 3-B** Nerve injury with a large defect treated with an intercalary sural nerve graft.

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or if EMG and NCS data suggest the presence of a neurapraxia or axonotmesis. Nonoperative management including supportive care, occupational therapy, physical therapy, and bracing should be employed during this interval.

Operative neurolysis should be considered if persistent symptoms are present at the nine-month point. However, if clinical, EMG, and NCS evidence of neurotmesis is identified, surgical management including a free intercalary graft reconstruction should be performed as soon as possible within the nine to twelve-month period after injury. Nerve fiber fibrosis occurs between twelve and twenty-four months after nerve injury, with full denervation potential at twenty-four months.

Summary

Multiple neurological complications of sports-related surgery have been documented previously in both the upper and lower extremities. Preventive measures can be employed to minimize these potentially devastating injuries. Palpable surface landmarks should be well marked prior to portal and incision placement. Joint position, including knee or elbow flexion, can be adjusted to maximize protection against nerve injury. Joint distention with fluid may be beneficial by displacing vital structures from their position near a portal placement site. Tourniquet time should be minimized. If neural defects exist postoperatively, follow a rigorous evaluation process and construct an appropriate management plan based on the aforementioned guidelines. These guidelines should be used to facilitate an efficient and accurate clinical evaluation and to construct an individualized treatment algorithm to optimize patient outcomes. ■

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