EMPOWERING THE SURGEON

New Neuroprotective and Neuroreconstructive Techniques

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CHECKPOINT SURGICAL™

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The Checkpoint® Nerve Stimulator/Locator is a single-use, sterile device intended to provide electrical stimulation of exposed motor nerves or muscle tissue in order to locate and identify nerves and to test nerve and muscle excitability.

Do not use the Checkpoint Stimulator when paralyzing anesthetic agents are in effect, as an absent or inconsistent response to stimulation may result in inaccurate assessment of nerve and muscle function.

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This manual is designed to guide the diagnosis and treatment of nerve injuries. The manual is not intended to replace sound clinical judgment or meticulous surgical technique.

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EMPOWERING THE SURGEON:
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INTRODUCTION

Few things rival the sinking, nauseating feeling on morning rounds when your patient asks why they can't move or feel their fingers or foot. The prospect of years of recriminations (if not actual litigation) is so disheartening and the thought of the patient's loss of function so devastating, that one cannot help but ask, "How and why did this happen?"

Nearly all surgeons inadvertently inflict a nerve injury at some point in their career. The question we ought to ask, prospectively, is, "What can I do to avoid that problem?" Fortunately, there are precautions that can increase the margin of safety.

The intent of this manual is to tell the story of the evolution of neuroprotective techniques during surgery and how this evolved into using intraoperative stimulation to help make wiser decisions about treating injured nerves. While most of the examples are related to orthopedics, given my background, the basic principles apply to many otolaryngology, plastics, neurosurgical, general surgical, and urologic procedures as well.

Preventing iatrogenic injury to nerves is, of course, central to the concept of neuroprotection. However, the techniques extend beyond protection. The intraoperative use of a handheld stimulator that produces safe, accurate, reproducible stimulation, also affords the surgeon invaluable information about the treatment of nerve injuries, including information that is not available by any other means, including electrodiagnostic studies and electromyography. One such example, discussed in this manual, is the management of a neuroma-in-continuity, where it is unclear whether an intrafascicular neurolysis would be beneficial or if grafting or a nerve transfer is required. Intraoperative nerve stimulation by the surgeon can help make this critical choice between neurolysis and reconstruction by means of graft or transfer. Thus, use of intraoperative nerve stimulation can provide proximate information about the condition of the nerve that is, relative to nerve conduction studies, more reliable and less ambiguous.

Nerve injury is a justifiably feared complication of surgery, and the incidence rate is likely underreported. Litigation is common and results in awards or judgments against the surgeon in more than 75% of cases. Recent data in the orthopedic literature[1] emphasizes the magnitude of the problem. The most frequent cause of a lawsuit is “failure to protect” a structure and the structure involved is, in the vast majority of circumstances, a nerve. Malpractice awards now exceed $4 billion. Furthermore, the literature[2] now clearly and unambiguously states that the standard of care is that the surgeon must demonstrate that he or she has considered the integrity of the nerves and has actively made an effort to avoid a nerve injury. Failure to do so now constitutes not meeting the accepted standard of care.

Preventing iatrogenic injury to nerves is, of course, central to the concept of neuroprotection. However, the techniques extend beyond intraoperative protection, beginning with pre-surgical planning, including careful examination, documenting function, imaging, and electromyography (EMG) testing. Once the surgical plan is determined, the surgeon can identify what nerves may be at risk given the procedure and specific approach chosen. During surgery, I utilize the Checkpoint® Nerve Stimulator/Locator (Checkpoint Surgical, Inc., Cleveland, OH) to provide additional intraoperative information and adjust my preoperative plan, as necessary. Finally, stimulation is used at the end of the case to verify that nerve function is the same or improved, in the case of a neurolysis, prior to incision closure. This confirmation is then specifically documented in the surgical notes, providing a record of my neuroprotective measures. It is my hope that this manual’s focused review of representative case examples highlighting specific neuroprotective surgical techniques will encourage further thought and discussion on this expanded view of neuroprotection.

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[1]Matsen FA, Stephens L, Jette JL, Warme WJ, & Posner KL (2013). Lessons regarding the safety of orthopaedic patient care: an analysis of four hundred and sixty-four closed malpractice claims. The Journal of Bone and Joint Surgery (American), 95(4), e201–8. http://doi.org/10.2106/JBJS.K.01272

[2]Morris LGT, Ziff DJS, & DeLacure MD (2008). Malpractice litigation after surgical injury of the spinal accessory nerve: an evidence-based analysis. Archives of Otolaryngology--Head & Neck Surgery, 134(1), 102–107. http://doi.org/10.1001/archotol.134.1.102

BRIEF REVIEW OF IATROGENIC NERVE INJURY

Iatrogenic nerve injury can be devastating and significantly impact function as well as being a recognized source of pain. The prognosis for a nerve injury depends on the severity of the damage. A neuropraxia has the best prognosis, with recovery a near certainty, while a neurotmesis will not recover at all without surgical reconstruction. Usually, however, the injury is a stretch or crush resulting in an axonotmesis, which involves actual disruption of the axons with an indeterminate prognosis. If the damage is relatively mild and there is some continuity to the internal neural structure, some degree of regeneration may occur. However, if a damage threshold is exceeded, and there is internal disruption of the nerve architecture, then internal scarring will occur, resulting in a neuroma-in-continuity. This is the most common level of injury and frequently results in a treatment dilemma. What, if any, is the capacity for recovery without intervention, should the neuroma be excised and the nerve grafted, or should a nerve transfer be performed? This is a common and very challenging dilemma. If one elects to wait for spontaneous recovery and it does not occur, then the best chance for surgical reconstruction is lost because of irreversible motor end plate degeneration. On the other hand, if the internal axonal tube structure is still intact, then excising the neuroma will abrogate any regeneration potential which would likely lead to a better outcome than grafting or nerve transfer. There is just no way to know with certainty the best option. However, we will explore how surgeon-controlled, intraoperative nerve testing can be helpful in this common situation.

Protecting the nerve from injury during surgery is, of course, essential, and the surgeon’s anatomical knowledge, skill and care are, of course, paramount, but they do not necessarily immunize the surgeon from damaging a nerve. Confounding factors, such as previous surgery, scarring, infection, tumor growth and trauma, may annul and frustrate even concerted efforts by great surgeons to avoid nerve injury. Surgical techniques can also increase the risk of nerve injury. Positioning of the patient can cause increased traction or compression of the nerve, which over the course of a long procedure can lead to decreased nerve function. This type of injury can also be caused by excessive or prolonged retraction.

Additionally, the choice of surgical approach can result in placing certain nerves at greater risk of nerve injury. Nerves are also at risk of injury when using electrosurgical tools, which can cause a direct insult to nerve function, or may indirectly cause thermal injury. Nerves are also at risk when implanting or removing hardware or when selecting implant size. Tourniquet usage or paralytics decrease nerve and muscle function and thus, can cause false or misleading responses when using stimulation or monitoring technology.

GENERAL PRINCIPLES IN NEUROPROTECTION

ANESTHESIA AND TOURNIQUET

As a general principle, muscle relaxants should be avoided, as paralysis does not allow for the confirmation of a motor response when using intraoperative stimulation. Fortunately, most orthopedic, plastic, and ENT procedures can (and should) be performed utilizing a non-depolarizing anesthetic that does not cause muscle paralysis. In this way, intraoperative stimulation of suspect neural structures may be performed. The surgeon should always ask the anesthesiologist if any paralytic agent was used. It is important to ask specifically, as the anesthesiologist may not be familiar with the surgeon's preference or may say that a paralytic was just used for induction. Succinylcholine is, indeed, short acting. However, recovery from other agents, such as vecuronium, may be prolonged, invalidating the stimulation technique.

Furthermore, if a tourniquet is used and has been inflated after the paralytic agent is given, the effect may be difficult to reverse, either because the reversing agent cannot reach the limb or, even if the tourniquet has been deflated, the paralyzing drug may have become so strongly bound to the receptors in the ischemic limb that its paralyzing effect is prolonged and more difficult to reverse. Thus, the anesthesiologist may report normal twitches in the face, where they test, but there may be no response in the limb, thus potentially giving the surgeon a falsely negative test for a nerve. This is very important to understand and take into account.

Even without the use of paralytic agents, the tourniquet will eventually render the muscles unresponsive to stimulation. This effect is gradual. One can generally rely on 20-50 minutes of normal response to electrical stimulation after the tourniquet has been inflated. After that, there is a gradual decrease in the responsivity, which is highly variable from patient to patient. Thus, in planning the operation, if the nerves may be at risk, the surgeon should plan the operation to prioritize identifying, dissecting, if necessary, and protecting the nerves prior to the onset of tourniquet paralysis. If the dissection cannot be safely completed in that time, a 15-20 minute period of reperfusion should restore normal responsivity. If there is any doubt about lingering effects of paralytic drugs or tourniquet palsy, direct muscle stimulation using the 20 mA setting on the Checkpoint will demonstrate whether or not the muscles are responsive.

One other anesthesia-related issue concerns the use of stimulation with regional blocks. There is a misconception that nerves cannot be stimulated if a nerve block is performed. This is not the case. Local anesthetic blocking agents, such as lidocaine, carbocaine and bupivacaine, act locally on the nerves at the site of injection. While they block afferent and efferent signals in the area where the nerves are exposed to the anesthetic agent, the nerve remains fully functional in areas not touched by blocking agent. The only area of the nerve that will not be responsive is that zone directly bathed by the drug. For example, if a scalene block is performed, as is frequently done for shoulder surgery, normal responses to stimulation are seen distal to the block, so the posterior and lateral cords, axillary, radial and median nerves and everything distal can be stimulated with normal responses. Thus, stimulation can be used with regional anesthesia.

A corollary to this is that if a procedure is done with local anesthesia, as is increasingly popular, and care is taken to not spill the xylocaine or other drug on the nerve, then the nerve can be stimulated [using the 0.5 mA (milliamp) setting]. If low intensity stimulus is used with a mixed motor/sensory nerve, the motor zones can be distinguished from the sensory portion of the nerve, with the patient reporting a tingling or mild electrical shock when the sensory fibers are stimulated.

INTRAOPERATIVE STIMULATION WITH THE CHECKPOINT STIMULATOR

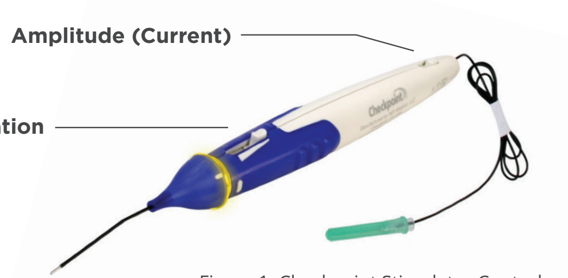

Figure 1: Checkpoint Stimulator Controls.

The intensity of the stimulation is determined by the two slide switches on the Checkpoint (Figure 1). The current control at the base of the instrument controls Amplitude and is marked in 0.5 mA, 2 mA and 20 mA intervals. These can be considered as “gross” adjustments for stimulating a nerve, around a nerve, or an entire muscle. The second adjustment controls pulse duration (pulse width) and is a continuously adjustable switch closer to the stimulating tip end of the device. This continuous adjustment from 0 to 200 microseconds (μsec) allows for fine and precise adjustment of the stimulus intensity at a fixed amplitude setting. The specific use of the controls is described below and in the case examples.

As a general rule, 20 mA is used only for regional stimulation and to stimulate muscle, and can be used to produce a sustained, tetanic, proportionally controlled contraction of the muscle from approximately 0-4/5 strength. The 20 mA setting is not typically used for direct nerve stimulation. It will not injure a nerve, but could produce a very forceful muscle contraction in a normally functioning nerve. The 20 mA setting can be used to stimulate a muscle to help identify dissection planes (see Shoulder section) or to “model” the postoperative result of a muscle or tendon transfer (see biceps to triceps transfer: Video 11).

The 0.5 mA and 2 mA ranges are used for nerve dissection and evaluation. At 20 mA, the stimulator can produce a response if the nerve is within approximately 1-1.5 cm of the stimulation point (this is variable based on the density or type of tissue surrounding nerve structures, and recommendations are based on my experience with the device). Thus, the stimulator can be used to roughly identify the “zone” containing the nerve by starting with high stimulation

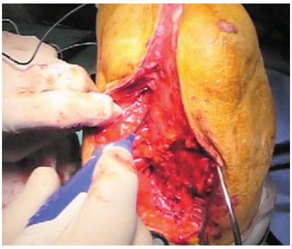

Figure 2: Regional Stimulation to hone in on nerve location in multiple revision elbow procedure.

intensity and then reducing to low stimulation intensity (Figure 2). The dissection can then proceed to "hone in" on the exact location of the nerve by progressively decreasing the stimulation intensity.

The 0.5 mA range is used for direct stimulation of a nerve. It is helpful to confirm that a structure in question is a nerve and to assess its function. In my experience a normal, uninjured nerve will produce a substantial muscle contraction in the 0.5 mA range and 25-50µsec of pulse duration. This is important to note when a decision must be made as to whether or not the nerve is functioning normally.

The lower end of the 0.5 mA range (<50µsec) is used for intraneural dissection. This low-level stimulus is very specific with very little "spread" into adjacent areas and, therefore, it is useful for an intraneural dissection, such as that performed for dissecting the donor nerve to be used for a nerve transfer (Figure 3).

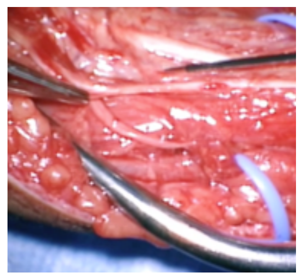

Figure 3: Stimulation to assist with fascicle identification during intraneural dissection.

SPECIFIC APPLICATIONS AND CASE EXAMPLES

SHOULDER

Protection of the axillary and musculocutaneous nerves (as well as the brachial plexus) during open or arthroscopic shoulder dissection is critical. Many of these surgeries occur in patients with a history of multiple operations, decreased active and passive range of motion of the joint and subsequent anatomical changes to the anatomy. In addition, excessive scar formation is also common, increasing the concern for nerve protection and assessment. In some wellmuscled or previously operated individuals, it can even be difficult to find the deltopectoral interval as the muscles appear confluent. Misidentifying the correct interval can lead to dissection medial to the strap muscles by mistake and damage to the lateral cord, axillary, or radial nerves. Use of the Checkpoint at the low end of the 20 mA range (<100μsec pulse duration) allows stimulation of the deltoid and pectoralis major muscles at the beginning of the dissection, and the distinct lines of pull can be seen to help identify the correct interval (Video 1). The same can be done for the strap muscles. In our experience, failure to develop the correct interval and deviating medially is the most common cause of injury, as nerves are indiscriminately clamped in an effort to control bleeding.

Video 1: Deltopectoral interval identification with stimulation.

Revision Shoulder Arthroplasty

Video 2: Reverse shoulder arthroplasty

Case 1 illustrates the use of the Checkpoint to revise a failed ORIF of a fracture dislocation to a reverse total shoulder arthroplasty (Video 2). The specific challenges in this case are: scarring due to the injury as well as the previous surgery, the risk to the radial nerve during the dissection to remove the plate and screws in order to allow the humeral component's stem to be inserted, and some concern about the integrity and function of the axillary nerve because of deltoid weakness.

The deltopectoral interval is scarred from the previous approach and the Checkpoint is used to help identify the correct interval by stimulating the pectoralis major and the deltoid using the 20 mA setting. As the strap muscles are exposed, the 2 mA setting is used to probe medial to the strap muscles, as the pectoralis minor is released and the musculocutaneous nerve is localized using the Checkpoint stimulator in the 2 mA range. If the strap muscles can be released, the dissection is much easier, although most surgeons prefer to protect the straps which are thought to help stabilize a reverse shoulder arthroplasty. If the muscle origins on the coracoid process are to be protected, a larger "window" is opened medial to the coracoid so that the lateral and posterior cords of the brachial plexus can be identified. Their identity is confirmed by stimulation, which can usually be done in the 0.5 mA range, although 2 mA should be used if it is difficult to find the nerves. The axillary artery can be palpated and the posterior cord is found slightly superior and posterior (deeper) to the artery. The bifurcation of the axillary nerve, branching off the superior aspect of the posterior cord, and the radial nerve (inferior part of the posterior cord) is seen.

The axillary nerve is dissected laterally, beneath the strap muscles, as far as possible. Once this is done, dissection lateral to the straps is done. This area may be heavily scarred and the Checkpoint can be used to stimulate tissue prior to cutting to confirm that the nerve is being protected (2 mA setting). This portion of the dissection may be difficult, especially because of the circumflex vessels that must be identified and either ligated or protected. The nerve is dissected beneath the inferior edge of the subscapularis and the glenohumeral joint. In this manner, a radical resection of the anterior, inferior, and postero-inferior capsule can be performed and we believe this helps with pain and rehabilitation, improving the final range of motion.

Next, the condition of the nerve is checked. While the patient's preoperative examination showed a functioning deltoid muscle, it is often difficult to know how well the muscle is functioning due to contractures and pain. The exact incidence of axillary nerve dysfunction is not known, but it is likely higher than expected, especially in fracture/dislocation cases. Because the reverse TSA is so dependent upon the deltoid, we routinely check the function of the axillary nerve with the Checkpoint and, if the responsivity is less than normal, an external epineurotomy/ectomy is performed. Normally, stimulation of the axillary nerve in the 0.5 mA range at 50-100μsec of pulse duration will produce a good deltoid response. If this is not seen, the thickened and scarred epineurium is incised and partially resected until a normal response is seen at 0.5 mA and <100μsec pulse duration. This gives more accurate information than preoperative electrodiagnostic studies that are inferential and cannot directly stimulate the nerve or provide information about the threshold stimulus. This is a great advantage of enabling the surgeon with a "pocket electrophysiology lab" in the form of the Checkpoint.

Once the axillary nerve is functioning normally, the "threshold stimulus" is determined. This is done in the 0.5 mA range, as the pulse duration slider is slowly increased until a muscle response is just seen. The pulse duration is noted on the Checkpoint LCD display and the preparation of the bone and insertion of the trial

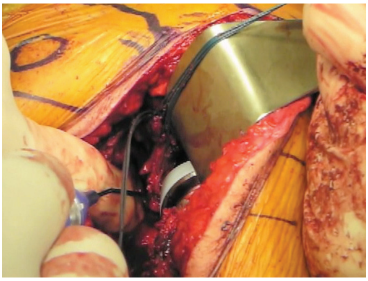

Figure 4: Threshold testing to assess nerve function with trial components.

components is done. With the trial components in place, the axillary nerve is stimulated once again at the same threshold stimulus level (Figure 4). If a response is not seen, the pulse duration should be increased until a response is seen. If it requires more than a very slight increase in pulse duration to provoke a deltoid contraction, then the nerve is being stretched and, stability permitting, the components should be downsized until the threshold is back to normal. Note that in testing the threshold, the same area of the nerve should be stimulated, as there may be some variation, depending upon how much epineurium has been resected. Finally, at the conclusion of the case, the integrity of the nerve should be tested once again with the stimulator so that the dictation may note that the nerve worked normally at the conclusion of the case.

Musculocutaneous Neuroma-in-continuity

Video 3: Neurolysis of musculocutaneous nerve.

The Checkpoint is also very helpful for intraoperative decision-making in cases of nerve injury. This case involves a young athlete who underwent a Latarjet procedure for recurrent instability (Video 3). Postoperatively, the patient lost all musculocutaneous nerve function and could not actively flex the elbow.

Upon exploration, an area of damage to the nerve was seen and a decision made regarding neurolysis vs. nerve grafting and reconstruction. Preoperative nerve conduction (NCS) and EMG tests were not helpful in that they showed fibrillation potentials and signs of denervation, but did not offer any further information about the degree of damage. Therefore, I used the Checkpoint to obtain an intraoperative assessment of nerve function to determine the condition of the nerve, as the preoperative NCS was ambiguous (Figure 5).

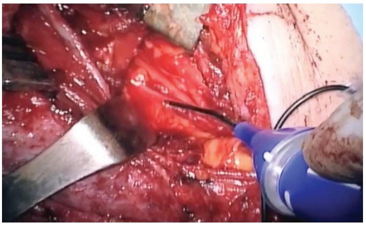

Figure 5: Intraoperative assessment of musculocutaneous nerve function.

The neuroma-in-continuity was carefully dissected under the operating microscope. After external neurolysis, intact fascicular groups could be traced across the zone of injury and, after completion of a meticulous, but gentle, neurolysis, an unambiguous biceps response could be seen in the 2 mA range and a trace of a contraction could be seen in the 0.5 mA range. My "rule of 2", while not rigorously validated, suggests that if any response is seen in the 2 mA range, at least motor grade 3 recovery will occur, and a neurolysis, rather than transfer or grafting, is the appropriate procedure. Furthermore, if any response, even a trace flicker, can be elicited in the 0.5 mA range, then the patient will likely make a full recovery, with restoration of normal strength. The decision regarding how to treat a neuroma-in-continuity is always a challenge and intraoperative use of the Checkpoint can provide extremely valuable, proximate information to help make the correct decision. This applies not only to the shoulder, but also to nerve injuries throughout the body.

Rotator Cuff Repair

Direct muscle stimulation using the 20 mA setting may even be useful in procedures like arthroscopic and open rotator cuff repair. If there are doubts about the condition and contractility of the cuff muscles, or even difficulty distinguishing between cuff and scar tissue, which can happen with failed, previous repairs, intraoperative nerve stimulation can help. Often, given the extensive scarring, it is difficult to discern cuff and tuberosity fragments from scar tissue. In an open procedure the Checkpoint can be used at the 20 mA setting, stimulating directly on the muscle and increasing the pulse duration from 0 to 200μsec, while directly observing the tendon or muscle response. This can also be done in an arthroscopic procedure by placing the stimulator probe through a small incision, utilizing the arthroscope to confirm location of the muscle and stimulating using the same parameters as above. This is shown in Figure 6 and Video 4, where the Checkpoint is being used to stimulate the supraspinatus and infraspinatus muscles. The Checkpoint is inserted through a small incision into the supraspinatus or infraspinatus fossa. The 20 mA setting is used to stimulate

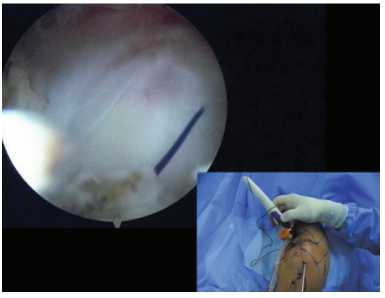

Figure 6: Stimulation through small incision in arthroscopic rotator cuff repair.

the entire muscle and the pulse duration slider is gradually increased. The tuberosity fragment, with the attached supraspinatus tendon, is seen to contract well with good excursion and the cuff tendons can then be dissected free from the investing scar tissue and mobilized.

Video 4: Checkpoint use in arthroscopic rotator cuff repair.

A previously placed traction suture can be used to give a gross assessment of the muscle's contractile strength and excursion, which can help inform the decision about whether or not cuff repair is possible. Also, during endoscopic release of the suprascapular nerve, the Checkpoint can be used (with the 2 mA setting) to identify the nerve during the dissection.

ELBOW

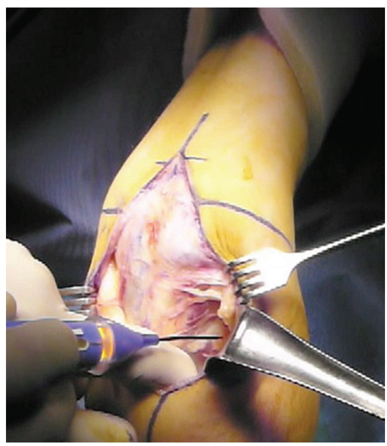

Figure 7: Regional stimulation to locate ulnar nerve in dense scar.

Dissection of the ulnar nerve is frequently a challenge around the elbow, particularly if there has been previous surgery and dissection around the nerve. Often, the degree of scarring is severe and it is difficult to discern the border between the nerve and the scar (as see in Figure 7), making the dissection risky. This problem is compounded if the neurological function is intact, as sometimes, even gentle dissection can affect the nerve's function, probably as a result of vascular compromise. Intraoperative stimulation can also be used around the elbow to identify and dissect the ulnar, median and radial/PIN nerves.

Nerve identification proceeds in a manner similar to the shoulder described above, using the Checkpoint in the 2 mA range to find the zone around the nerve and then progressively decreasing the stimulus intensity using the pulse duration slider until the nerve is precisely localized. If indicated, the function can be checked, recalling that a normally functioning nerve shows a good motor response in the 0.5 mA range. Suspicious areas of scar can be stimulated to determine if it is scar tissue or active nerve tissue.

On occasion, the nerve may be functioning well and it is desirable to protect the nerve but it is not necessary to actually dissect the nerve. An example would be the situation of aseptic loosening of a TEA (Video 5) . The patient's nerve has normal function, despite heavy scarring from previous surgery. In this case, it would be ideal to avoid actual dissection of the nerve, if the surgeon could be confident of the location and safety of the nerve. As shown in the case description, the path of the nerve is mapped, using the Checkpoint, without actually formally dissecting the nerve. Once the surgeon knows where the nerve is, then he or she can be sure of where it isn't, hence a safe location to incise. In this manner, the entire exposure can be safely performed without ever actually seeing the nerve. This saves considerable time, as well as sparing the nerve. At the conclusion of the procedure, the nerve can be stimulated proximally with the Checkpoint, observing the distal contraction, and the surgeon may dictate something to the effect, "At the conclusion of the case, the nerve was stimulated and a normal distal response was seen, confirming the integrity of the nerve."

Video 5: Revision total elbow arthroplasty.

Similarly, the median and radial nerves can be located and checked with the Checkpoint. Dissection of the median nerve is rarely necessary in elbow procedures as it is protected by the brachialis muscle. One exception to this is a chronic biceps tendon rupture, with a retracted, scarred biceps. The proximity to the median nerve, which may actually be scarred to the biceps stump, can be surprising. Safe repair requires identification and dissection of the median nerve before freeing the biceps and dissecting proximally to mobilize and restore elasticity to the muscle. This dissection, to completely mobilize the biceps, is important, as it may obviate the need for a tendon graft and, thus, lead to a better outcome. Intraoperative nerve stimulation can help facilitate this dissection not only by protecting the median nerve, but also can be used to identify the branches of the musculocutaneous nerve that innervate the biceps. In this manner, accidental damage to the biceps innervation can be avoided while achieving better muscle mobilization and function.

The radial nerve can be at risk in elbow surgery because of the proximity to the joint capsule anterior to the proximal radioulnar joint. A severe elbow contracture or heterotopic ossification can put the radial nerve at significant risk and the nerve may even go through a bone tunnel in the heterotopic bone. After a standard lateral approach, the Checkpoint may be used to localize and confirm the identity of the radial nerve. The safest way to do this is to look for the nerve proximally, in the groove between the brachioradialis and brachialis muscles. If this interval is not clearly seen, direct muscle stimulation at the 20 mA setting can be used in a manner analogous to the deltopectoral interval identification described in the shoulder section, to help identify the interval. In extreme cases, the nerve should be identified even more proximally, as it passes through the lateral intermuscular septum from posterior to anterior. The nerve is then dissected distally. At the bifurcation between the radial sensory nerve and the posterior interosseous nerve, the Checkpoint should be used to confirm the muscle response to PIN stimulation (Video 6) to prevent inadvertent confusion between the sensory and motor branches that could lead to accidental damage to the PIN, which is deeper and less apparent than the sensory branch.

Video 6:
PIN and radial nerve stimulation.

Another useful technique that can spare unnecessary proximal dissection is the “inside-out” dissection of the brachialis/brachioradialis interval. From the joint side of the capsule, a sulcus can frequently be palpated and the radial nerve can be exposed by incising the capsule and finding the nerve from within the joint. Once done, the anterolateral capsule can then be completely excised.

If the surgeon is dealing with an injured nerve, as in the example of a PIN injury during a distal biceps tendon repair, the “rule of 2’s” may be used to help with the decision of grafting versus neurolysis. In one example case, the PIN was apparently crushed by injudicious use of a baby Homan retractor. The PIN palsy was complete, but stimulation with the Checkpoint showed a minimal response so we elected to wait for nerve regrowth. While this took nearly a year, in this case, the final outcome was normal function in all muscles, including the EIP, which likely represents a better outcome than would be achieved with nerve grafting.

INTRAOPERATIVE NERVE STIMULATION IN ARTHROSCOPY

The Checkpoint can also be used to stimulate the nerve during arthroscopic procedures. However, stimulation in an aqueous environment, as with arthroscopy, requires direct nerve contact with the tip of the probe because of current dispersion and weakening of the stimulus in the conductive, wet environment. The 2 mA setting is recommended for this use. One example of this use is illustrated in arthroscopic rotator cuff repair described in the shoulder section above (Video 4).

INTRAOPERATIVE STIMULATION DURING BONE PIN INSERTION

Video 7: Stimulation to assist with bone pin insertion using a minimal incision.

As described above, nerves are often at risk of injury when placing hardware to stabilize fractures or improve joint function. While these procedures often involve larger incisions and exposures, nerves can also be at risk when using minimal incisions. Video 7 demonstrates use of the Checkpoint in a humeral lengthening procedure to ensure that nerve function is preserved. In this case, planned location of the proximal pins placed the axillary nerve at risk, while the radial nerve is at risk of injury due to the planned location of the distal pins. Minimal incisions were used to minimize cosmetic scarring, and the Checkpoint is used to probe the incision area to help locate and protect the axillary and radial nerves (Figure 8).

HIP

Figure 8: Stimulation in minimal incision to check nerves are not in path of hardware insertion.

Sciatic nerve injury rates associated with hip arthroplasty and revision are likely conservatively reported and as the rate of procedures has increased, so too has the rate of revisions. Injury is more likely in revision surgery and cases involving developmental dysplasia of the hip. In such cases, the nerve is vulnerable to traction injury because of lengthening of the leg. Revision THA also puts the nerve at some risk because of unclear anatomy and scarring around the nerve. This is particularly pronounced in cases requiring revision of a metal-on-metal prosthesis which can cause particulate discoloring and large pseudotumors.

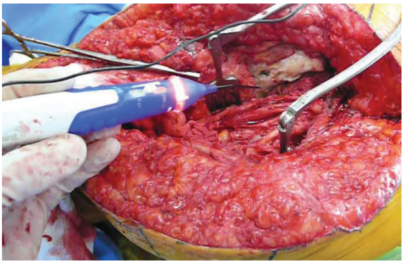

Figure 9: Regional stimulation for identification of sciatic nerve course.

The Checkpoint is used to identify the sciatic nerve, using the standard “zone” technique described above, where the stimulator is used at the 20 mA setting to identify the approximate zone of the nerve and then progressively decreasing the stimulation as the nerve is dissected and exposed (Figure 9). This can help prevent nerve injury by a Homan or other lever-type retractor inadvertently pressing against the nerve. If leg lengthening is anticipated, the nerve should be exposed and threshold testing performed to establish the minimum stimulus necessary to observe a distal motor response. This is similar to the technique described in the shoulder section to prevent overstretch of the axillary nerve. The stimulus threshold should be noted on the Checkpoint. After placement of the trial components, the nerve is retested. If the threshold stimulus required is increased, the components should be downsized and the threshold retested.

Video 8 illustrates a case of a total hip arthroplasty for developmental dysplasia of the hip. During the procedure, the threshold stimulus was found to increase with the trial components, but there was marked instability with the smaller components. The Checkpoint still elicited a distal motor response in the 0.5 mA range, although the upper limit was required (200μsec pulse duration). Based on this, the surgeon elected to use the larger components. The patient did have a peroneal branch sciatic palsy postoperatively, but the surgeon told the patient that, based on the intraoperative stimulation findings, that the neuropraxia would resolve shortly, as it did within 2 weeks with return of full function and strength. This

Video 8: Checkpoint use in total hip arthroplasty.

is a good example of using stimulation to help with intraoperative decision-making and avoid either a permanent injury to the nerve or the use of undersized components that would result in instability and would likely require revision because of chronic, recurrent dislocations.

HIP/SPORTS

Video 9: Stimulation to assist in repair of chronic hamstring avulsion.

Another common use for intraoperative nerve stimulation is illustrated in Video 9, a subacute hamstrings rupture. Often, this is done through a limited approach in the gluteal crease and, much like a chronic, retracted biceps tendon rupture, the proximity and adherence of the sciatic nerve to the scarred proximal stump of the tendon may not be appreciated. In fact, part of the pain of a chronic hamstring tear may be neurological, as we have been impressed by the amount of traction on the large, hamstring branches of the sciatic nerve caused by the distal retraction of the hamstring muscles. Also, some patients have reported improvement in the pain and a change in the nature of the pain immediately post-op, which might be related to alleviating the tension of the hamstrings on the sciatic nerve.

In these cases, the Checkpoint is used in the 20 mA range to roughly approximate the sciatic nerve's location, switching to the 2 mA range as soon as the nerve is grossly located. The amount of scarring can be impressive and the exposure is frequently less than optimal, especially in heavier individuals. The stimulator can then be used to identify the branches to the hamstrings, which are not easily seen because of scar tissue despite their relatively large size. These are freed and preserved as the retracted tendon stump is dissected and mobilized to reach back to the ischium.

TUMOR SURGERY

Biopsy

One of the most commonly injured nerves is the XI cranial (spinal accessory) nerve. The nerve is quite superficial and vulnerable during lymph node biopsy in the posterior triangle of the neck, and injury of the spinal accessory nerve results in trapezius paralysis. Surgeons frequently try to perform the biopsy under local anesthesia or full general anesthesia. The area is very vascular and bleeds, even with careful technique and precautions. The spinal accessory nerve is very, very superficial and easily injured in an effort to control bleeding or harvest the lymph node. Intraoperative nerve stimulation can be used to identify the course of the nerve and then perform a “stim-then-cut” technique to ensure that the lymph node biopsy does not also include a nerve biopsy. If the patient is noted to have trapezius dysfunction after the biopsy, immediate reoperation by a peripheral nerve surgeon would be recommended, as the cut nerve and muscle distal to the injury remain responsive for 7-10 days after the injury. Thus, early intervention would allow identification of the distal stump of the nerve (which can be very difficult) and permit early reconstruction with a nerve graft, which is not possible after a delay of more than about 10 days because the loss of responsivity in the distal stump of the nerve makes it impossible to identify.

Tumor Resection

Neurovascular injury is always a risk of tumor resection. In the case of malignancy, resection with adequate margins is, of course, the top priority and may require sacrifice of a nerve. However, nerves are also at risk in benign lesion and the dissection may benefit from intraoperative nerve stimulation. One relatively common example concerns a large neurolemmoma (Schwannoma) where the functioning fascicles may be widely splayed across the tumor. Separating these intact fibers may be difficult, but individual fascicular group stimulation with the Checkpoint in the 0.5 mA range will help the surgeon distinguish the fibers from the tumor and permit safe separation of the Schwannoma from the nerve for resection. Sometimes the fascicular bundles are so stretched across the surface of a large Schwannoma as to be virtually unrecognizable, but stimulation can help prevent damage.

Another example is illustrated in Video 10, involving an extremely large, bi-lobed lipoma involving the supraspinatus as well as infraspinatus fossa and putting the suprascapular nerve at risk in both areas, especially the spinoglenoid notch (Figure 10). During the dissection, exposure of the nerve is difficult. If the tumor is to be resected en bloc, stimulation can be used to distinguish nerve from the surface

Video 10:
Lipoma excision.

pseudocapsule of the tumor. The nerve may even be difficult to discern from the tumor's surface; the tissue that responds to stimulation is very carefully peeled away and protected as the tumor is removed.

Figure 10: Use of stimulation to locate and protect suprascapular nerve during excision of surrounding lipoma.

One final application of nerve testing in oncology concerns reconstruction. If a major nerve must be sacrificed in order to achieve an adequate margin, the Checkpoint can be used at the 0.5 mA setting to identify the motor fascicular groups. This should be done on the nerve proximal and distal to the resection site to grossly map the motor and sensory quadrants before dividing the nerve. If immediate reconstruction is possible (and this is ideal), the cable nerve grafts are sewn to the proximal stump and labeled for later connection with the distal stump. After tumor (and nerve) resection, stimulation can be used again on the distal stump to identify motor and sensory areas, which can then be matched to the motor and sensory grafts proximally. If, for some reason, the reconstruction must be delayed, marking the quadrants with fine sutures and covering the stumps with a silicone cap, that can be easily found, is a fallback solution. However, immediate reconstruction is much preferred.

TENDON TRANSFERS

The Checkpoint is helpful with tendon transfer surgery in two ways. The first is to confirm the contractility of the muscle. This is particularly important if the transfers are being performed for spinal cord injury, where there can be post-ganglionic damage that renders a muscle that should, according to the level of injury, be working, but may be unresponsive due to peripheral nerve damage aside from the central nervous system injury. Obviously, such a muscle is not suitable for transfer and it can be difficult to predict or even perceive intraoperatively if the muscle is available for transfer. Thus, for the spinal cord injury patient, the Checkpoint can be used to check the "stimulatability" or responsivity of muscles below the level of the cord injury. This is important if nerve transfers are considered, for example a musculocutaneous to median nerve transfer in a C5 tetraplegic. The ability of the median innervated flexors to contract should be confirmed with the Checkpoint (used in the 20 mA range for muscle or 2 mA if the nerve is exposed) prior to transfer. If the median innervated muscles are not responsive, presumably due to unrecognized peripheral nerve injury, the transfer cannot work and should not be performed. The incidence of this unrecognized peripheral injury remote from the level of the cord injury is unknown, but my experience suggests it may be more common than thought and may account for the variable results of transfer reported by Bertelli in applying nerve transfer techniques to spinal cord injury patients.

For non-spinal cord injury patients, intraoperative nerve stimulation can confirm the contractility of muscles intended for transfer. In essence, this is like performing “wide awake” surgery on a patient who needn’t be awake, if either the patient or surgeon prefers a regional or general anesthetic without losing the ability to observe muscle contractility. The usual stipulations about avoiding paralytics and long tourniquet times apply. Also, once the transfer is completed, the post-operative outcome can be “previewed” by stimulating the transferred muscle with the 20 mA setting on the Checkpoint. This is illustrated in the biceps-to-triceps transfer shown in Video 11, in which stimulation of the transferred biceps is performed to confirm tensioning and full elbow extension. This can help make the outcome of transfers more consistent.

Video 11: Direct muscle stimulation in biceps to triceps tendon transfer.

SUMMARY

Post-op rounds or that first post-op visit should be a moment of mutual excitement and maybe exultation with your patients. We want to be secure in the knowledge that our patients will do well and that we have made wise, informed treatment decisions and executed them well. Intraoperative stimulation with the Checkpoint to identify nerves and to assess the degree of injury and prognosis for recovery has become a core principle of my practice and a way to avoid sleepless nights.

Michael R. Hausman, MD

Dr. Hausman is the Robert K. Lippmann Professor of Orthopedic Surgery, Vice-Chairman of the Department of Orthopedics at Mount Sinai, and Chief of Hand and Upper Extremity Surgery for the Mount Sinai Health System. Dr. Hausman received his undergraduate and medical degrees, cum laude, from Yale University, interned in general surgery at the University of Colorado and returned to Yale for his orthopedic residency. He then received subspecialty training in hand surgery with the prestigious fellowship of Drs. J. William Littler and Richard Eaton in New York.

Dr. Hausman is an internationally recognized upper extremity surgeon who treats disorders of the hand, elbow, shoulder and peripheral nerves. He also performs microsurgical reconstruction of congenital, trauma, burn and neoplastic conditions throughout the body. He has pioneered the use of arthroscopy for treating pediatric elbow deformities and adult fractures and dislocations and has been invited to lecture on these topics throughout the world. He has also served as Chairman and Director and faculty for international courses in elbow arthroscopy and reconstruction in America, Europe, South America and the Middle East.

Dr. Hausman is board certified in orthopedic surgery and has the additional certification in surgery of the hand, a rigorous, additional qualification for subspecialists. He has served on the board of directors of the American Society for Surgery of the Hand and serves Mount Sinai in a variety of capacities, including chairman of the Professionalism Committee of the Faculty Council. He is a member of American Shoulder and Elbow Surgeons and the American Society for Reconstructive Microsurgery. Castle Connolly and New York Magazine have recognized him as one of the nation's and NYC's top doctors. He resides in New York with his wife and three children and enjoys cycling, reading and music.

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